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MONITORING ACTIVITY WITH A WRIST-WORN ACTIGRAPH: EFFECTS OF AMPLIFIER PASSBAND AND THRESHOLD VARIATIONS

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Monitoring activity with a wrist-worn actigraph:

Effects of amplifier passband and threshold variations

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SUMMARY

Problem.

Wrist-worn devices for monitoring general activity (actigraphs) have proven useful in many areas of research and clinical application. The AMA-32 actigraph is a highly programmable device with more than 40 different modes of operation. However, little is known about the utility of these different modes. Secondly, at the inception of this project, there was no user-friendly software for the extraction of research-grade data from actigraph data files.

Objective.

This project had two objectives: 1) development software permitting exploratory analysis of actigraph data and 2) preliminary assessment of the utility of various modes of operation of the AMA-32 actigraph during both sleep and wake, and in the differentiation of sleep from wake.

Approach.

A menu-driven program for the analysis of actigraph data was developed for operation on IBM-compatible computers. Actigraph data were collected from six subjects during a four-day experiment involving a simulated 10-hour shift in the sleep-wake cycle.

Results.

1) The *General Activity Analysis Program* (GAAP) includes a wide array of features of rapidly accessing and analyzing activity data. 2) Activity data are highly dependent on the passband selectivity and threshold of the actigraph. For the discrimination of sleep from wake, a midrange passband (2 to 3 Hz) with a high threshold voltage provides the best results. This setting emulates earlier-generation actigraphs. The use of other settings in sleep studies will require the development of new sleep-scoring algorithms.

Conclusions.

The AMA-32 is a highly versatile device with many advantages over earlier-generation actigraphs. Considerable developmental work will be required to fully understand its operation. The availability of GAAP will facilitate these efforts.

INTRODUCTION

Activity measuring devices are being used in a wide variety of clinical and field settings for assessment of both daytime activity and sleep. Clinical applications include the diagnosis and treatment of a variety of disorders including mood disorders, schizophrenia, hyperactivity in children, attention deficit disorders, sleep disorders, substance abuse, eating disorders, and chronic disease (Brown, Smolensky, D'Alonzo, and Redmond, 1990; Tryon, 1991). These devices are also being used in military research where the emphasis has been on assessment of sleep in field operations (e.g. Brooks, Shergold, Angus, Heslegrave, and Redmond, 1988; Pleban, Valentine, Penetar, Redmond, and Belenky, 1990). The purpose of the present study was to evaluate the utility of a newly designed, highly programmable type of actigraph (the AMA-32), which permits specification of several analog amplifier parameters.

To explore the properties of the AMA-32, it was first necessary to develop a computer program for the analysis of actigraph data. The *General Activity Analysis Program* (GAAP) provides rapid menu-driven access to actigraph data, quantitatively summarizes activity records, scores them for sleep, and outputs graphical and numeric data to the computer screen, printer, or data files.

In initial laboratory studies, effects of altering several amplifier parameters were investigated. Subjects lived in the laboratory for several days, undergoing a simulated time-zone shift. In addition to wearing actigraphs, brain activity was monitored during sleep, and the records were scored for sleep stages using standard techniques. As a result of these studies it was concluded that the 2 to 3 Hz passband, high threshold setting of the AMA-32 provides the best sleep/wake discrimination. Additional studies will be necessary to further evaluate the AMA-32 for other purposes.

Wrist-worn actigraphs

A variety of different devices have been used for measurement of activity, the most versatile being the AMA-16 actigraph produced by Precision Control Designs Inc., described by Redmond and Hegge (1985). The device measures approximately 6.4 x 8.9 x 1.9 cm and was attached to the wrist by a velcro wristband, using a solid-state accelerometer to detect motion. After processing by appropriate analog circuitry, the data are stored in a 16 Kbyte memory. The AMA-16 is programmed by inserting it into an interface unit which in turn is attached to an IBM PC-compatible microcomputer. This device has been used extensively in laboratory and field research (Brooks, Shergold, Angus, Heslegrave, and Redmond, 1988; Mullaney, Kripke, and Messin 1980; Konigsberg and Cushing, 1986; Tryon, 1991), and yields useful information about the impact of environmental stressors on patterns of sleep and wake. However, it has some drawbacks. It is large enough to cause difficulties in some environments. For example, some pilots refuse to wear the device because it interferes with the normal wearing of a tight-fitting flight suit (French, 1992), its memory capacity is only 16 Kbytes, thus limiting the amount of data that may be stored, and its recording parameters are fixed. That is, the frequency passband, threshold levels, and gain of the circuitry may not be changed.

A new generation of actigraphs (Precision Control Designs Inc., Model AMA-32) addresses many of the drawbacks of the AMA-16. This model is much smaller, measuring only 4.45 x 3.48 x 1.27 cm., about the size of a diver's watch. The memory capacity has been doubled to 32 Kbytes, making longer studies possible. It is highly programmable, permitting user specification of frequency passband, threshold, and amplification factors. This versatility theoretically should permit fine-tuning of measurements for specific purposes (e.g. daytime *vs* nighttime activity). Details of the available AMA-32 actigraph settings are shown in Appendix 1. However, severe

shortcomings exist both in information on the significance of the available AMA-32 settings as well as in methods for analysis of AMA-32 data. The purpose of the present project was to address these shortcomings in order to maximize the utility of the AMA-32 in laboratory, clinical, and field research settings.

SOFTWARE DEVELOPMENT

The lack of user-friendly software has been a significant impediment to the widespread application of actigraph technology. In fact, at the beginning of the present project there was *no* user-friendly software for the derivation of research-grade data from actigraph data files. Programs do exist for clinical applications of actigraphy, but these programs lack the versatility necessary for the types of exploratory analyses desired for research purposes. Thus, the first step in this project was the development of a software program for the derivation of research-grade data from actigraph data files. GAAP permits rapid analysis of data files generated with either AMA-16 or AMA-32 actigraphs. The program is described in detail in Appendix 2. The principal features of GAAP are:

1. Graphical display of activity at two levels of resolution
2. Daily or hourly summaries of sleep and activity
3. Daily or hourly distributions of activity data
4. Multiple sleep-scoring algorithms
5. Sleep scoring editing capability
6. Screen, printer, or file data output
7. Epoch-by-epoch data file output
8. Graphics file output for hard-copy plots of activity
9. Mouse-driven user interface

GAAP enables individuals with no programming expertise to quickly access and analyze activity data, generate figures, and produce output appropriate for analysis by conventional statistical and spreadsheet programs. This program is available upon request from the senior author or may be downloaded from the OMPAT computer Bulletin Board (registraton: 301 427-5455; BBS 800-542-7844).

SYSTEMATIC EXPLORATION OF AMA-32 PARAMETERS

While a complete exploration of the possibilities presented by the AMA-32 was not possible in this project, to begin the process of defining the utility of this device, a number of subjects were run as part of a larger experiment.

Method

Subjects and Procedure

Data from seven young adult, male, civilian volunteer subjects will be reported. The subjects were participants in a study of the effects of bright light on adaptation to a simulated time-zone shift. As part of the study, EEG recordings were made during four eight-hour sleep periods. During the study, each subject continuously wore two actigraphs on his nondominant wrist for up to 96 consecutive hours. The actigraphs were each set to the same frequency passband with a high gain, differing only in threshold, and were operated in zero-crossing mode (see Appendix 2 for more details on actigraph operating modes). Amplifier settings used are shown in Table 1 (see Appendix 1 for more details on the available amplifier settings).

Table 1 -- Amplifier Settings

Subject	Settings	Passband (Hz)
BL201	5, 6	.1 to 3
BL203	5, 6	.1 to 3
BL205	9, 10	.1 to 9
BL206	9, 10	.1 to 9
BL207	17, 18	2 to 3
BL208	17, 18	2 to 3
BL210	19, 20	2 to 9

Results

Although there will be some overlap, descriptions of results will be divided into five sections: 1) general effects of passband and threshold variations 2) activity during wake 3) activity during sleep 4) sleep/wake discrimination and 5) automatic discrimination of sleep from wake. Because of the exploratory nature of this project and the large amount of data collected, representative selected data will be presented in the body of the paper and more detailed data will be provided in appendices.

General effects of passband and threshold variations

As indicated by Redmond and Hegge (1987), the effects of alterations in the analog sensitivity of the circuitry of the actigraph are quite complex and not easily characterized. However, the data collected in this study permit some generalizations. Figure 1 illustrates complete actigraph records from two subjects. The left column is from Subject BL203, whose two actigraphs were set for a passband of 0.1 to 3 Hz, and the right is from Subject BL208 whose actigraphs were set for a 2 to 3 Hz passband. The top row is for the actigraphs with a low-threshold setting, and the bottom row is for the high-threshold actigraphs. In these figures, each line represents activity for a full day, from 1200 to 1200 hours. All records were plotted on the same scale.

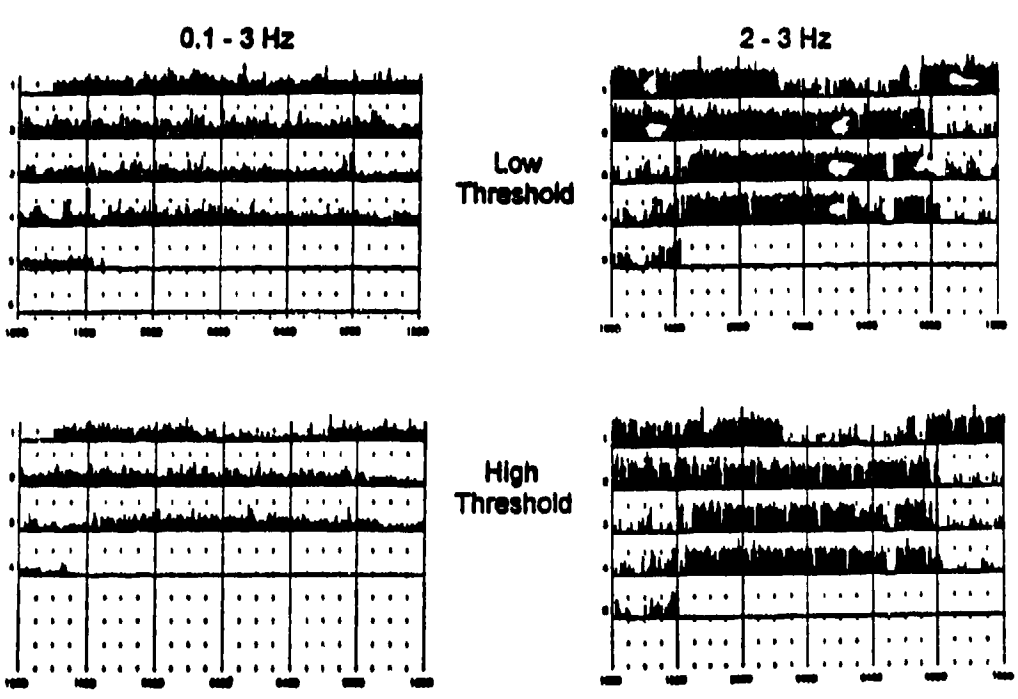

Figure 1. Complete actigraph records for subjects 203 (passband, 0.1 to 3 Hz) and 207 (passband, 2 to 3 Hz). The top and bottom rows represent low and high threshold actigraphs, respectively.

There was a clear difference in overall activity levels between the two passbands, with considerably more activity shown for 2 to 3 Hz than for 0.1 to 3 Hz. The other two subjects with these amplifier settings showed the same effect to approximately the same degree. This finding is somewhat counterintuitive, since 0.1 to 3 Hz is a broader passband than 2 to 3 Hz and thus should accumulate more movements. However, this simplistic notion does not take the complex nature of the signal generated by the motion transducer in the actigraph into account. Recall that the actigraphs were operated in zero-crossing mode, in which the beginning of a movement is defined as occurring when the voltage from the transducer exceeds the threshold. The low end of the 0.1 to 3 passband is sensitive to very slow movements (i.e., 1 movement / 10 sec); thus, when a

slow movement begins (i.e., the voltage exceeds the threshold), faster movements will not register, since the threshold voltage has already been exceeded. Hence, fewer total counts may be registered when the passband includes extremely low frequencies.

A second phenomenon that is apparent from Figure 1 is that, during sleep, more counts are registered with the 0.1 to 3 Hz passband than with the 2 to 3 Hz passband. On Day 1, the sleep period was from 2200 - 0600 hours, and on subsequent days, it was from 0800 - 1600 hours. In some cases it is quite difficult to visually distinguish sleep from wake in the raw activity records with the 0.1 to 3 Hz passband, whereas the sleep periods are quite clearly visible with the 2 to 3 Hz passband. Complete activity records for all subjects are attached to this report as Appendix 3. Inspection of the records for subject BL210 (Appendix 3) suggested that his actigraphs were not functioning reliably, hence his data must be regarded as highly preliminary.

Figure 1 also illustrates an effect of threshold, which, for these passbands, resulted in less activity for the higher threshold than for the low threshold. However, this was not always the case. The probable reason for this is illustrated in Figure 2 which shows a hypothetical activity waveform and three different thresholds. If the activity waveform were a perfect sinusoid, varying the threshold would have a binary effect, that is, either a movement would register or not, and lower thresholds would result in more movements being counted. However, movements do not produce perfectly sinusoidal waveforms. In this figure, choosing thresholds A or C would result in the registration of two movements. However, choosing threshold B would result in six movements being counted. When the additional factors of amplifier gain and passband are considered, the relationships become even more complex.

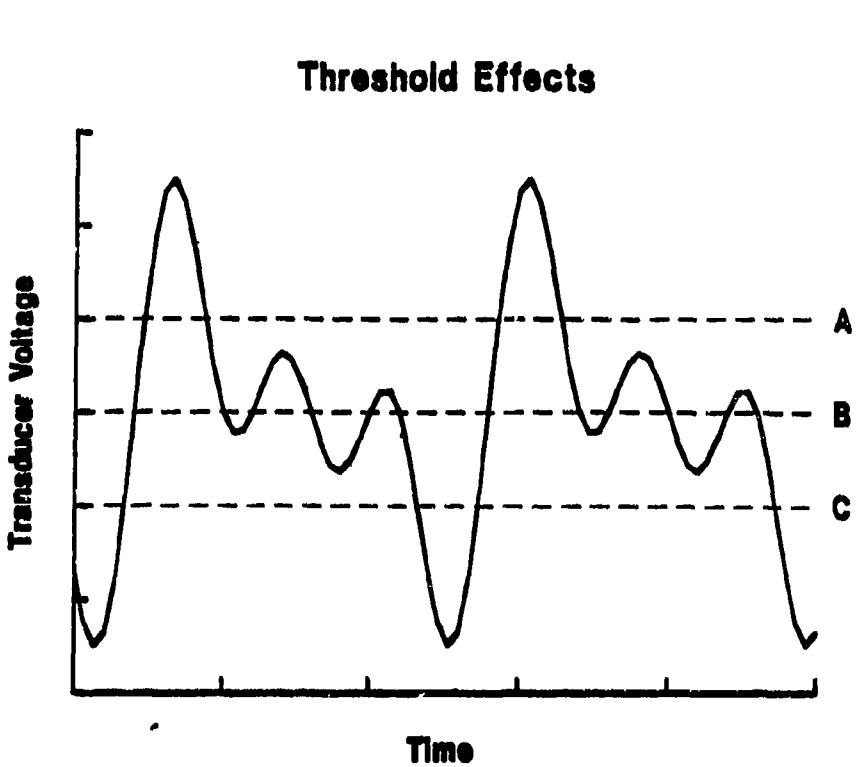

Figure 2. Hypothetical waveforms of actigraph transducer voltage output illustrating effects of varying thresholds on recorded movement frequency.

Waking activity

Assessment of daytime activity has been largely confined to summaries of hourly or total daily activity (Tryon, 1991). These measurements have been useful in distinguishing between various groups, such as normal and depressed patients (eg., Godfrey and Knight, 1984), hyperactive and normal children (eg., Porrino, Rappoport, Behar, Sceery, Ismund. and Bunney, 1983), and drugged vs control patients (eg., Mattman, Loepfe, Scheitlin, Schmidlin, Gerne, Strauch, Lehman, and Borbely, 1982). With more detailed analysis, it should be possible to detect treatment effects with greater precision.

Table 2 presents summary descriptive statistics for individual subject activity during three "days," with Day 1 representing the 24-hour period beginning at 0800 following the first night of sleep in the laboratory. No sleep was permitted during this period. Days 2 and 3 were 16-hour periods beginning at 1600 following the first and second daytime sleep periods. Subject BL203's high-threshold actigraph failed during the third day. Table 2 shows that in most cases the day-to-day reliability of the actigraphs was quite high, with daily variations in mean activity generally within 15 percent of the three-day mean. Agreement between subjects for comparable actigraphs (e.g. BL201, low threshold vs. BL203 low threshold) was similarly high, with no more than a 10 percent difference between the three-day mean score for each subject and the mean of the two three-day scores for both subjects. This table also shows a reasonable degree of agreement between the means and medians of movements per epoch, indicating that the movements per epoch distributions are reasonably uniform.

Table 2
Movements per epoch for continuous waking activity

Passband	Subject	Threshold	Day	Mean	SD	Median	Q1	Q3
0.1-3 Hz	BL201	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	24.52	10.50	24	18	30
			3	25.28	11.67	23	18	32
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	19.37	10.00	19	13	26
			3	21.51	9.22	21	16	27
	BL203	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	19.10	9.56	17	13	23
			3	19.96	9.37	19	14	24
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	18.09	9.75	18	12	23
			3	*	*	*	*	*
0.1-9 Hz	BL205	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	29.09	15.44	27	19	37
			3	41.57	19.41	40	30	54
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	37.20	17.41	37	26	48
			3	30.05	15.30	31	22	39
	BL206	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	45.33	19.69	44	31	58
			3	43.26	18.54	43	32	56
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	34.85	15.78	33	24	45
			3	36.60	18.06	35	25	48
2 to 3 Hz	BL207	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	54.38	21.77	62	47	68
			3	47.41	25.87	58	26	66
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	36.57	23.25	41	16	57
			3	36.96	22.75	41	17	56
	BL208	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	50.96	21.13	58	42	56
			3	50.48	21.16	57	37	56
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	34.48	21.86	36	15	54
			3	31.77	21.43	31	13	52
2-9 Hz	BL210	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	80.70	17.66	83	76	90
			3	82.03	9.91	82	77	88
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	52.99	23.01	59	37	71
			3	57.20	21.05	64	42	74

This uniformity of distributions is also evident in Figure 3 in which the medians and interquartile ranges (IQR) of movements per epoch are displayed. In most cases, the IQR bars extend approximately equally above and below the median. The most marked asymmetries occur when the medians are highest, (i.e., for the 2 to 3 Hz, low threshold actigraphs). This figure also illustrates that for the 2 to 3 Hz, high threshold actigraphs, the IQRs are quite large, indicating that the distributions are relatively flat. This point will be further illustrated in the sleep/wake section.

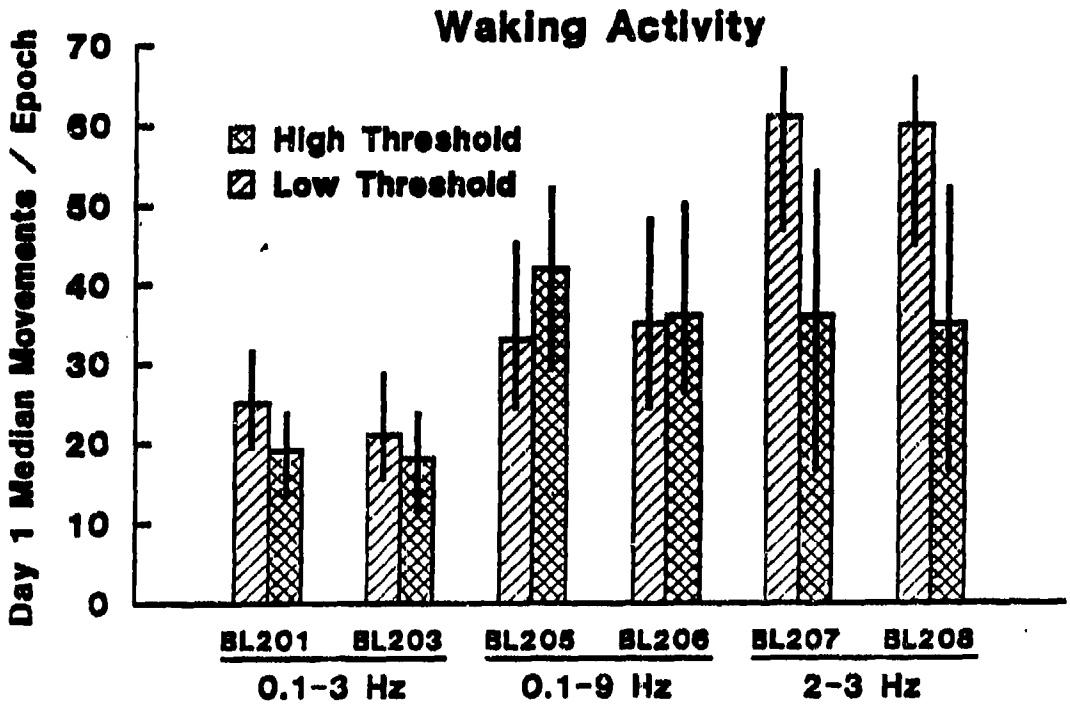

Figure 3. Median movements per epoch. The heavy vertical lines on each bar span the interquartile range.

In addition to the summary statistics presented thus far, consideration of actigraph records as time series provides another set of approaches to data analysis that may prove useful in addressing issues related to daytime activity patterns.

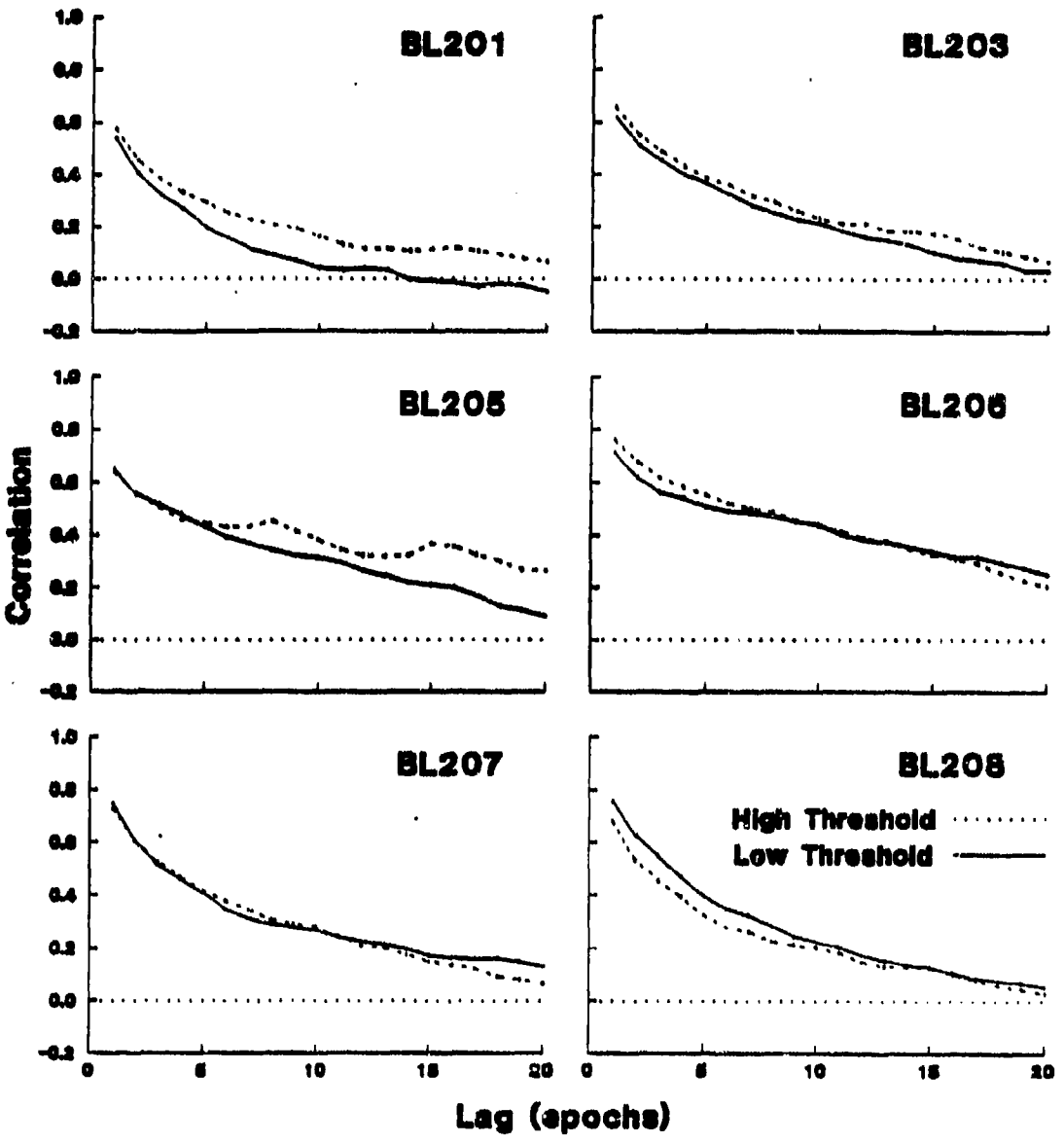

Figure 4. Autocorrelation functions for six subjects for 24 hours. Each row represents two subjects with the same passband setting.

Examples of two time series analysis techniques are be provided. One approach to time series analysis is autocorrelation which assesses the degree of correlation between increasingly distant epochs. Figure 5 shows autocorrelation functions for both high- and low-threshold actigraphs for Day 1. Correlations are plotted for lags 1 to 20, where lag 1 represents immediately adjacent epochs, and lag 20 correlates epochs that were 20 epochs (10 minutes) apart. These functions all have the same general shape, with the correlation between epochs decreasing as the distance between the epochs increases. The functions are all quite smooth and orderly, indicating that there were no short-term periodicities (i.e., period less than 20 epochs) in the data. There was also good agreement between each subject's actigraphs, athough for both BL201 and BL205 the autocorrelation functions for the high threshold actigraph were consistently higher than that for the low threshold actigraph.

Figure 5 shows the results of submitting the data from Day 1 to a Fourier analysis (Fast Fourier Transform or FFT). In all cases, the power or magnitude is greatest at the higher frequencies (periods less than 20 minutes). Figures 4 and 5 are presented here merely to illustrate the type of data that can result from time series analyses. It remains for more extensive studies to determine the degree to which such analyses may be useful in assessment of the effects of other variables of interest on activity.

Activity during sleep periods

Summary statistics for each subject for three eight-hour sleep periods are presented in Table 3. The first sleep period was from 2200 on Day 1 to 0600 the following day. Subsequent sleep periods began at 0800. For simplicity, sleep periods will be referred to as "nights." Thus, Night 2 began following 26 hours of time awake. Since the low threshold actigraph for Subject BL210 registered an extremely large increase in

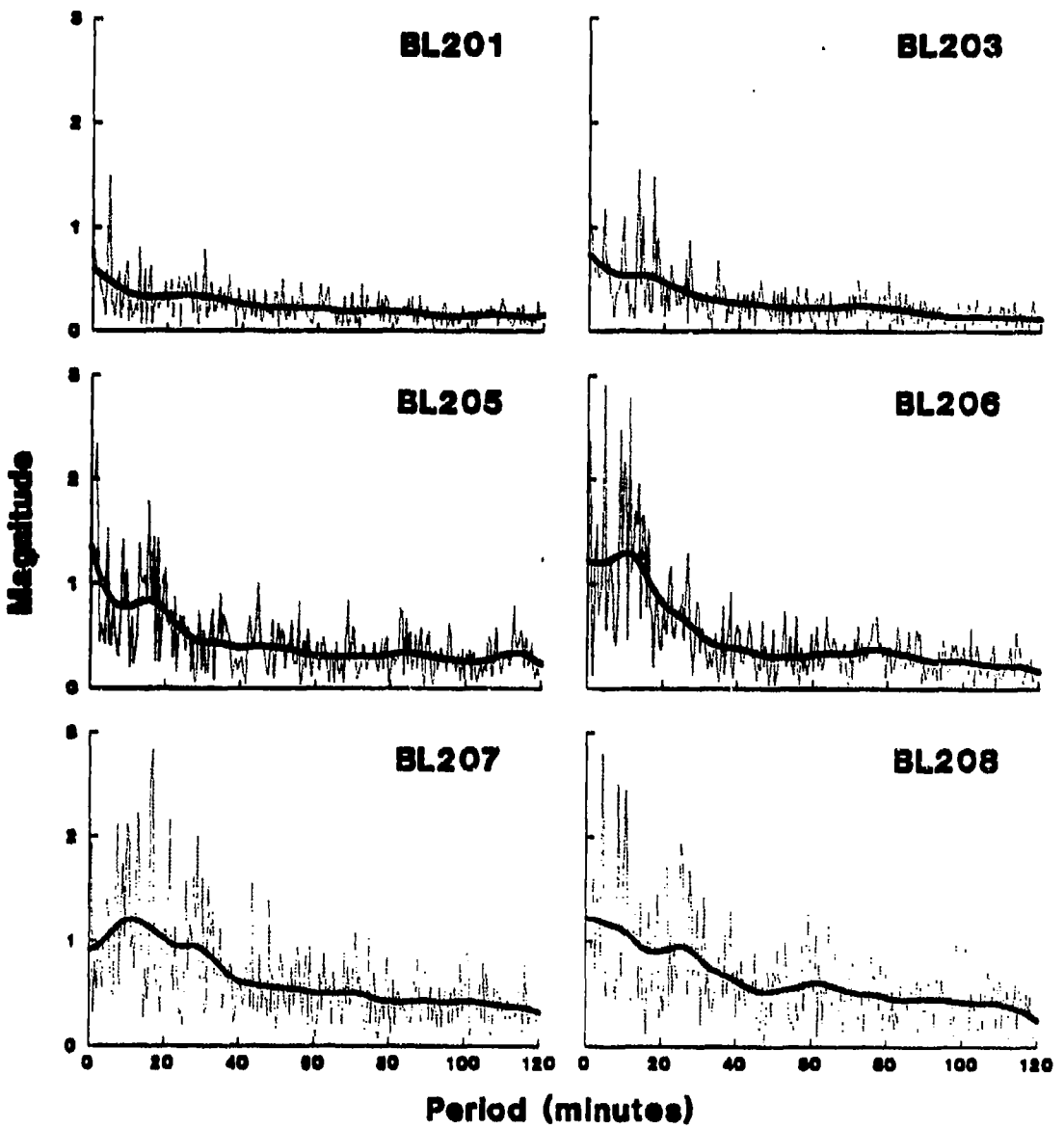

Figure 5. Periodograms for 24 hours of waking activity.

movements during the last two nights, it is assumed that device was malfunctioning, thus, those data will be discounted.

In most cases, the stability of activity across nights was less than that seen above during wake, with several examples of greater than 50 percent night-to-night differences. There was also little consistency in the pattern of changes across subjects. The degree to which this variability reflected the effects of the experimental protocol is not clear from the present data. It is strikingly clear from Table 3, however, that the overall activity level was least for the 2 to 3 Hz passband, particularly so for the high threshold actigraphs. The median number of movements recorded by these actigraphs was consistently zero during sleep periods, thus the movement distributions are highly asymmetrical. On the other hand, the other passbands all continued to have fairly uniform distributions. Figure 6 shows these effects graphically by plotting the medians and interquartile ranges of movements per epoch from Night 1.

Table 3
Movements per epoch during sleep periods

Passband	Subject	Threshold	Sleep Period	Mean	SD	Median	Q1	Q3
0.1-3 Hz	BL201	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	16.53	10.30	13	7	24
			3	16.95	7.72	15	11	22
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	11.04	7.21	11	6	15
			3	7.38	4.56	6	5	9
	BL203	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	23.88	11.82	22	15	30
			3	16.18	10.65	13	9	20
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	6.82	6.54	6	2	10
			3	7.65	7.31	6	1	13
0.1-9 Hz	BL205	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	8.77	13.81	3	1	8
			3	54.55	23.22	52	38	67
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	11.07	10.88	9	3	16
			3	8.61	10.96	5	1	12
	BL206	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	51.95	17.99	53	41	64
			3	49.22	18.86	53	33	64
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			2	20.66	11.58	20	14	28
			3	18.45	10.47	20	10	26
2 to 3 Hz	BL207	L	1	11.20	15.00	3	0	19
			2	7.37	9.98	4	0	11
			3	12.09	14.82	6	1	19
		H	1	3.17	9.71	0	0	0
			2	1.49	6.13	0	0	0
			3	4.92	13.08	0	0	1
	BL208	L	1	6.31	12.84	1	0	6
			2	4.11	11.60	0	0	2
			3	5.40	10.19	0	0	6
		H	1	2.13	7.13	0	0	0
			2	2.21	8.90	0	0	0
			3	1.29	4.85	0	0	0
2-9 Hz	BL210	L	1	5.07	9.52	0	0	8
			2	72.02	17.14	74	61	84
			3	92.18	13.59	91	82	102
		H	1	30.16	20.81	25	13	57
			2	12.12	12.57	10	3	17
			3	23.01	17.13	20	11	32

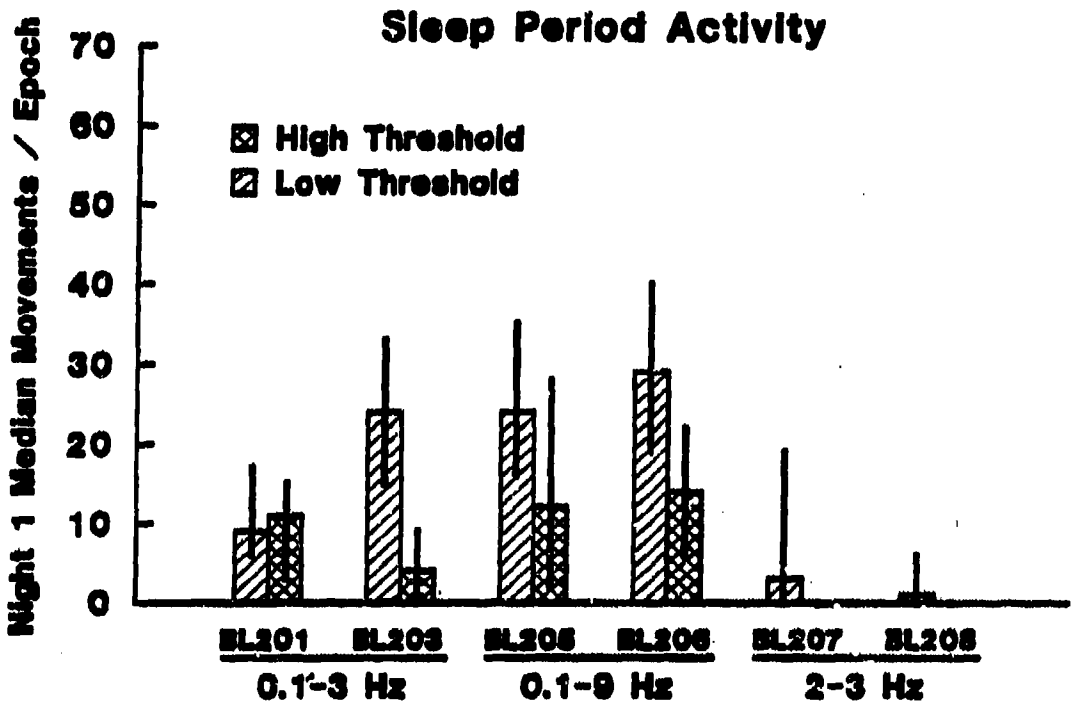

Figure 6. Median and interquartile ranges of movements per epoch from Night 1.

Sleep-wake discrimination

The raw data displays illustrated in Tables 1 and 2, Figure 2, and Appendix 3 provide a broad overview of activity across several days. A more focused look at the data is illustrated in Figure 7 which dramatically illustrates the effect of amplifier passband on movement frequency distributions during one 24-hour period (Day 1). These figures plot the number of epochs containing a given number of movements as a joint function of number of movements and time of day, with movement frequency going from left to right, and time of day going from front to back. The top graph is data from subject BL201 with a passband of 0.1 to 3 Hz, and the bottom is from BL207 with a 2 to 3 Hz passband. In the top frame, the movement frequency distribution during waking periods

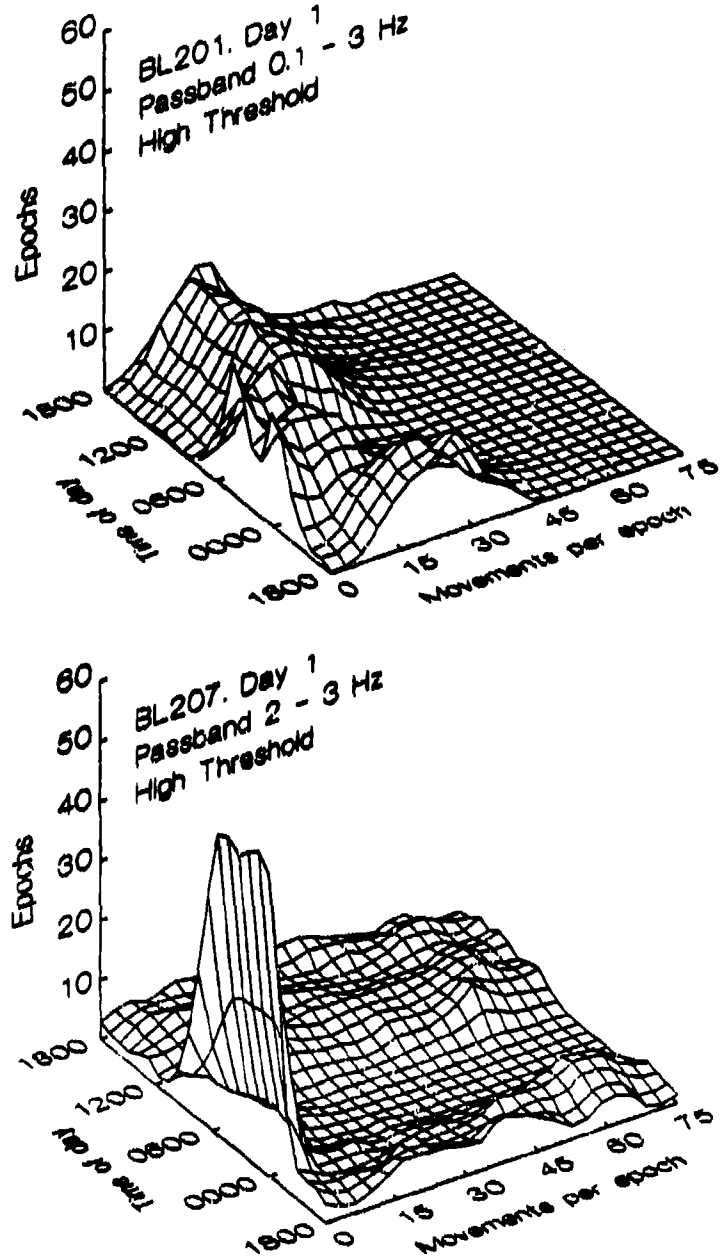

Figure 7. Movement frequency distributions for two actigraphs on day 1. See text for an explanation.

was fairly uniform, with a peak in the neighborhood of 20 movements per epoch. During the sleep period (2200 to 0600), the distributions shifted to the left, occasionally peaking at zero movements during sleep. The bottom graph shows a much clearer difference between sleep and waking distributions, with the waking distributions showing no clear peak, and the sleep distributions unambiguously peaking at zero. Appendix 4 presents similar plots for each subject for the three 24-hour periods of the study beginning at 1800 on Day 1.

To further clarify the differences between passbands and thresholds in sleep/wake discrimination, Table 4 shows the average sleep/wake ratios for nights 1 - 3. The values were obtained by dividing mean movements per epoch from a given night by mean movements per epoch for the following day.

Table 4
Sleep/Wake Ratios

Passband (Hz)	Subject	Low Threshold	High Threshold
0.1 to 3	BL201	0.61	0.47
	BL203	1.05	0.37
0.1 to 9	BL205	0.84	0.33
	BL206	1.04	0.49
2 to 3	BL207	0.19	0.09
	BL208	0.10	0.06

Two effects are suggested by the data in this table. First, regardless of the passband, in *all* cases the ratios are lower for the high threshold than for the low threshold. Secondly, as was suggested by Figure 7, the ratios are *much* lower for 2 to 3 Hz than for the other passbands, suggesting that the 2 to 3 Hz passband is the band of choice for distinguishing sleep from wake.

Automatic discrimination of sleep from wake

There have been a variety of efforts to develop computer programs to automatically discriminate sleep from wake based on actigraph data (Cole and Kripke, 1988; Cole, Kripke, Gruen, Mullaney, and Gillin, 1992; Kripke, Webster, Mullaney, Messin, and Fleck, 1983; Mullaney, Kripke, and Messin, 1980; Pleban, Valentine, Penetar, Redmond, and Belenky, 1990; Sadeh, Alster, Urbach and Lavie, 1989; Webster, Kripke, Messin, Mullaney, and Wyborney, 1982). All of these techniques involve derivation of complex weighted sliding averages to determine whether a given epoch is to be scored as sleep or wake. These techniques perform reasonably well, typically achieving 80 to 90 percent agreement with polygraphically scored sleep. Actigraphic sleep scoring systems typically fail, that is they incorrectly score epochs as sleep during periods of low activity during the day (reading or watching TV), and during sleep onset (depression in movement prior to onset of EEG-defined sleep) (Elsmore, 1992; Tryon, 1991).

The data in this paper show that activity measurements are heavily dependent on the amplifier settings (i.e. passband, threshold, and presumably gain, though that was not varied in this study) of the actigraph. Thus, algorithms for automatic determination of sleep from activity data will similarly be dependent on amplifier settings. The studies cited in the preceding paragraph used actigraphs whose analog characteristics approximated setting 18 of the AMA-32 actigraph. Thus, in the present study, the extant activity/sleep algorithms can only be expected to apply to the data obtained with that setting, that is, the high threshold actigraphs for Subjects BL207 and BL208. Table 5 summarizes the results of applying three different sleep-scoring algorithms to these data from the first three sleep periods. All three algorithms were developed for data collected in 60-sec epochs. Since in this study, the data were collected in 30-sec epochs, successive

epochs were combined prior to applying the algorithms. Standard EEG records were collected during all sleep periods, and the records were scored for sleep stages according to the criteria set forth in Rechtshaffen and Kales (1968). For purposes of comparison with the actigraph-based scores, all epochs scored as sleep stages 1 to 4 and REM were considered sleep.

Table 5
Comparison of EEG and actigraph-based sleep measures

		Epochs scored as sleep				Percent agreement with EEG-based scores		
Subject	Night	EEG	A1	A2	A3	A1	A2	A3
BL207	1	850	908	920	682	93.5	92.2	75.4
	2	806	940	942	746	82.7	82.5	71.0
	3	904	870	888	650	86.2	87.2	65.0
BL208	1	845	930	930	696	89.6	89.2	72.6
	2	786	926	926	744	79.5	79.5	69.5
	3	750	960	956	694	78.1	78.1	63.3

A1 = Cole & Kripke
A2 = Sadeh et al.
A3 = Walter Reed

These data confirm the reports in the literature (Cole and Kripke, 1988; Cole, Kripke, Gruen, Mullaney, and Gillin, 1992; and Sadeh, Alster, Urbach and Lavie, 1989) that actigraphs can produce sleep data that is around 80 to 90 percent in agreement with EEG-based sleep measures when subjects are known to be in bed. The Walter Reed algorithm (Pleban et al., 1990) was much less accurate, yielding only around 65 to 75 percent accuracy. The probable reason for this is that this algorithm considers only the absolute activity level for the past five minutes, while the other two algorithms are much more context-sensitive, allowing for the normal movements that occur during sleep.

However, this feature also makes these algorithms more likely to produce false positives when the subject is known to be awake.

Table 6 shows the percent of epochs scored as sleep by all three algorithms when the subjects were known to be awake. Day 1 data represents the 24-hour period from 0800 following the first sleep period to 0800 on the next day. Days 2 and 3 represent the 16-hour periods commencing at 1600 on subsequent days. This table shows that the algorithms that perform best when the subject is known to be in bed and trying to sleep, perform worst when the subject is known to be awake. In this case, the Walter Reed algorithm is clearly superior.

Table 6
Percent of epochs incorrectly scored as sleep

Subject	Day	A1	A2	A3
BL207	1	12.2	26.0	3.5
	2	18.1	27.3	8.8
	3	16.2	26.5	8.2
BL208	1	9.7	26.4	1.8
	2	14.2	25.2	5.2
	3	17.5	32.3	3.3

Discussion and Conclusions

The initial goal of this project was to thoroughly evaluate the utility of the new features of the AMA-32 actigraph in both daytime and sleep recording. The first thing that became apparent was the lack of adequate software for analysis of actigraph data for research purposes. Hence the first year of the project was devoted to developing a general-purpose activity data analysis program that operates on IBM-compatible PCs. GAAP is the result of that effort, and copies will be provided by the senior author upon

request. This program will enable widespread use of actigraph technology in both the military and civilian research and clinical communities, which, until now, were required to either enlist the services of an actigraphy specialist, write custom software to analyze actigraph data files, or purchase expensive commercial software designed for clinical applications.

The AMA-32 is a highly programmable device. The amplifier can be set to five different passbands, with high or low gain and high or low threshold. In addition, the device can operate in zero-crossing mode or time-above threshold mode, 40 possibilities in all. The present study surveyed only six of these possibilities, three passbands with either high or low thresholds, with high-gain setting in all cases. The passbands chosen represented low to medium (0.1 to 3 Hz), medium (2 to 3 Hz), and low to high (0.1 to 9 Hz) frequencies. Only the zero-crossing mode was used.

The clearest result of this study was that of the passbands and thresholds used, for discrimination of sleep from waking activity the medium (2 to 3 Hz) passband with high threshold (setting 18) was clearly superior to the other five combinations tested, even with the limited numbers of subjects in the study. Interestingly, this set of parameters most closely mimics that of the earlier, nonprogramable AMA-16 actigraph. The credit for this clearly goes to Daniel Redmond and Frederick Hegge of the Walter Reed Army Institute of Research who did the developmental engineering for the AMA-16 (Redmond and Hegge, 1987).

The effects of threshold variations were also fairly clear, with higher thresholds usually producing fewer counts and showing more sensitivity to sleep/wake conditions [see discussion of Figure 2 for explanation of the opposite possibility]. However, circumstances may exist when lower thresholds may be preferable. For example, if one is

interested in movement during sleep, a high threshold may produce a floor effect, limiting the usefulness of the data.

In the present study, daytime activities were highly circumscribed. That is, the subjects were confined to a laboratory with little opportunity for physical activity. If one is interested in changes in daytime activity, nontraditional actigraph parameters may yield more useful data. In the absence of relevant research this issue remains unresolved.

Given the great differences produced by varying the actigraph parameters, it became obvious that attempts to apply automatic sleep-scoring algorithms to data obtained with nontraditional actigraph parameters would not be meaningful. It is possible that new algorithms for processing these data could yield estimates of sleep parameters superior to the existing ones. This also remains a topic for future research.

It must be noted that the sleep-scoring algorithms that were surveyed are far from perfect. Those that performed well when the subjects were known to be in bed, produced many false positives (i.e., scored waking epochs as sleep) when the subjects were known to be awake, and vice versa. This is clearly an area in which a new approach is needed, particularly when accurate partitioning of sleep from wake is required. Two possible candidates are neural networks that are trained to discriminate sleep from wake, and sliding pattern recognition techniques.

Actigraphy is becoming a useful tool in the assessment of human behavior for clinical and research purposes. The AMA-32 is a device with great, though unrealized potential. A great deal of work remains to be done to fully understand how to best utilize this device. GAAP provides the researcher and clinician with easy access to activity data, and the data presented here represent a beginning.

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Appendix 1: AMA-32 amplifier settings

Option	FR	G	T	Option	FR	G	T	Option	FR	G	T
1	.1-1	H	L	8	.1-3	L	H	13	2 to 3	L	L
2	.1-1	H	H	9	.1-9	H	L	14	2 to 3	L	H
3	.1-1	L	L	10	.1-9	H	H	19	2-9	H	L
4	.1-1	L	H	11	.1-9	L	L	20	2-9	H	H
5	.1-3	H	L	12	.1-9	L	H	15	2-9	L	L
6	.1-3	H	H	17	2-3	L	H	16	2-9	L	H
7	.1-3	L	L	18	2-3	H	H				

FR: Frequency response in HZ
G: Gain, L=5; H=26
T: Threshold, L=6mV; H=24mV

Appendix 2

General Activity Analysis Program (Version 1.0): User's Guide

GENERAL DESCRIPTION

The General Activity Analysis Program (GAAP) was designed for the analysis of data files generated with the AMA-32 actigraph manufactured by Precision Control Designs Inc. (PCD) of Ft. Walton Beach, FL. It will also work with files generated by the AMA-16 actigraph, also manufactured by PCD. It provides a means of quickly viewing and summarizing activity data, application of sleep scoring algorithms to the data, generating epoch-by-epoch ASCII files, and generating hard copy tabular ASCII and graphical (HPGL) output files. The program runs on IBM-compatible PCs and requires a VGA monitor and a mouse.

GAAP is (almost) entirely menu-driven, with menu selections made by pointing and clicking the mouse. This file is available for help on-line. However, it is hoped that the program menu choices would be intuitively obvious, enabling the knowledgeable user to quickly master the fundamentals and get on with the real work. If this is not the case, this Users Guide should help close some of the gaps in GAAP.

GAAP MENU STRUCTURE

I. MAIN MENU
- A. Input New File
- B. Process Data
  1. Sleep Scoring
     - a. Cole & Kripke
     - b. Sadeh et al.
     - c. Walter Reed
  2. Set Markers
  3. Display/Edit
     - a. Wide View $
     - b. Zoom/Edit

4. Quit

C. Output
1. Display/Edit (same as above)
2. Sleep Periods !
   a. Sleep Summary by Day
   b. Sleep Summary by Hour
   c. Distributions by Day
   d. Distributions by Hour
3. Wake Periods !
   a. Summary by Day
   b. Summary by Hour
   c. Distributions by Day
   d. Distributions by Hour
4. HPGL Output File $
5. Epoch-by-epoch File
6. Quit

D. Help

E. Quit

II. SCALE MENU
A. Auto Scale
B. Force Scale

III. OUTPUT DESTINATION MENU
A. Screen
B. Printer
C. File

Note:

$ Automatically calls Scale Menu

/ Automatically calls Output Destination Menu

MENU DETAILS

I. MAIN MENU

A. Input New File. The user will be prompted to set the path for data files, initially set to the default directory. A list of all "DAT" files is then displayed. Highlight the desired one, and double-click to select.

B. Process Data.

1. Sleep Scoring. Implements three published algorithms for scoring sleep from activity data. All scoring is done using 60-second epochs since that is the way the algorithms were written. To see the results, use the display/edit option, the output sleep options, or the epoch-by-epoch file option.

a. Cole, R. J. and Kripke, D. F. (1988). Progress in automatic sleep/wake scoring by wrist actigraph. *Sleep Research*, 17, 331.

b. Sadeh, A., Alster, J., Urbach, D., and Lavie, P. (1989). Actigraphically based automatic sleep-wake scoring: Validity and clinical applications. *Journal of Ambulatory Monitoring*, 2, 209-216.

c. Pleban, R. J., Valentine, P. J., Penetar, D. M., Redmond, D. P., and Belenky, G. L. (1990). Characterization of sleep and body composition changes during Ranger training. *Military Psychology*, 2, 145-156.

2. Set Markers. The "markers" are times the program needs to do its business. The markers and defaults are as follows:

Marker	Value	Use
1. Day start time:	1200	Time at which 24-hour plots begin
2. Analysis start (hour):	1800	2 to 5 are not used
3. Analysis start (day):	1	
4. Analysis end (hour):	1200	
5. Analysis end (day):	6	
6. Sleep period start:	2200	Begin sleep summary
7. Sleep period end:	0600	End sleep summary
8. Wake period start:	0600	Begin wake summary
9. Wake period end:	2200	End wake summary

3. Display/Edit. Screen displays of activity data.

a. Wide View. Displays up to 10 full days of data, one day per line. If a sleep scoring algorithm has been run, the epochs scored as sleep will be displayed in red immediately below the line for each day.

b. Zoom/Edit. Displays 12 hours of data, one hour per line. File can be paged through by clicking on "Forward" and "Back" buttons. Using the mouse, minute-by-minute activity scores are displayed. Results of the sleep-scoring algorithm are also displayed below each epoch (red=sleep). The sleep scores can be edited using the mouse. Pressing the left button sets the sleep score for the current epoch to sleep, and the right button sets it to wake. If no sleep scoring has been done to the present file, all epochs will be set to sleep.

4. Quit. Returns to main menu

C. Output

1. Display/Edit. Same as No. 3 above

2. Sleep Periods. This provides summaries of activity only during the period of time bracketed by markers 6 and 7. The OUTPUT DESTINATION routine will automatically be called. If FILE output is chosen, the default file name will have the same name as the input data file, with the extension "SLP." (See III below for more on file names.)

a. Sleep summary by day. Minutes of sleep and wake, number, mean duration, and longest sleep episode, total activity counts, mean, standard deviation, first quartile, median, and third quartile of counts per epoch.

b. Sleep summary by hour. Same as a., but hourly.

c. Distributions by day. Displays a distribution (14 bins + overflow bin) for each day of counts per epoch. Bin size is selectable, and the user is queried regarding bin size each time this routine is run. The default is 10. Thus, bin 1 has the number of epochs containing 0 to 9 counts, bin 2, 10 to 19, etc.

d. Distributions by hour. Same as c., but hourly.

3. Wake Periods. Summaries of activity only during the period of time bracketed by markers 8 and 9. As above, the OUTPUT DESTINATION routine will automatically be called. If FILE output is chosen, the default file name will have the same name as the input data file, but it will have the extension "WAK."

a. Summary by day. Total activity, mean, standard deviation, first quartile, median, and third quartile of counts per epoch.

b. Summary by hour. Same as a., but hourly.
c. Same as 2c above.
d. Same as 2d above.

4. HPGL output file. Produces a file of HPGL (Hewlett Packard Graphics Language) commands which will generate a hard copy of the "wide view" display discussed above (I.B.3a.). This file can be interpreted by any number of graphics programs, or printed by utilities such as PRINTGL, which is a shareware program. The file can also be directly printed on a HP pen plotter. These files will have names like "name.plt" where name is the same as the "DAT" file being processed. (i.e. if the data file is "ACTIVITY.DAT", the plot file will be "ACTIVITY.PLT." These files tend to become VERY long, easily reaching 450 Kbytes in length. Thus they should either be deleted after use or archived, then deleted to prevent cluttering the hard disk. This routine also automatically calls the SCALE MENU.

5. Epoch-by-epoch File. Creates an ASCII file with one record per epoch. Fields in the record are:
epoch number
time of day
number of counts
sleep score (1=wake, 0=sleep)
NOTE: If no sleep scoring has been done, this field is eliminated.
The output filename will be the same as the input file name, but will have the extension "ASC." Again, these files can become very long, so good disk hygiene is warranted.

6. Quit. Return to main menu.

D. Help. Reads this file on-line.
E. Quit. Exit program.

II. SCALE MENU. This menu allows the user to set the scale for 24-hour displays or plots. The scale value will be plotted as 80 percent of the distance between successive days on the multi-day plot.

A. Auto Scale. The scale value is set to the maximum value in the input file.
B. Force Scale. If several plots are to be compared, this is the preferred method, since it will allow them all to be plotted with the same scale. The input value is retained between plots.

III. OUTPUT DESTINATION MENU. Called by all routines discussed above in I.C.2 to I.C.4 above.

A. Screen.

B. Printer. No form feed is sent. Thus, multiple calls can print data on the same sheet of paper.

C. File. If the same file name is used in successive calls, the new data will be APPENDED to the old, permitting the user to build up a data file with results from multiple subjects, multiple runs from the same subject, different marker parameters, etc.

GAAP Restrictions

1. "DAT" FILES ONLY. PCD provides the program "PCD.EXE" which can save data in either of two formats, "PCD" or "DAT." The PCD format is the more compact of the two, since it stores the data in a "packed" fashion, very much the way it is actually stored internally in the actigraph memory during data collection. The DAT format expands the data such that the activity from each epoch is stored as 2 bytes (16 bits), making decoding of the data much simpler. If the data were saved in PCD files, the user must be read it into the PCD program and written back out as DAT files.

2. SLEEP SCORING FOR 30- AND 60-SECOND EPOCHS ONLY. A truly general program would not have this restriction, but due to the fact that the extant sleep algorithms require a one-min epoch, the decision was made to keep this restriction. For sleep analysis with 30-sec epochs, data from successive 2-epoch blocks is used.

3. VGA ONLY. The graphics routines in GAAP require VGA.

4. MOUSE REQUIRED. GAAP accepts and requires keyboard input in a few places.

An Actigraph Primer

The AMA-32 actigraph is a wristwatch-sized device which records movement. The AMA-16 is somewhat larger. The active element in the device is called an "accelerometer" which is essentially a weighted arm attached to a piezoelectric crystal. When stresses are placed on the crystal by movements of the weighted arm, it generates an electrical voltage, much like the needle of a phonograph does when it is displaced by

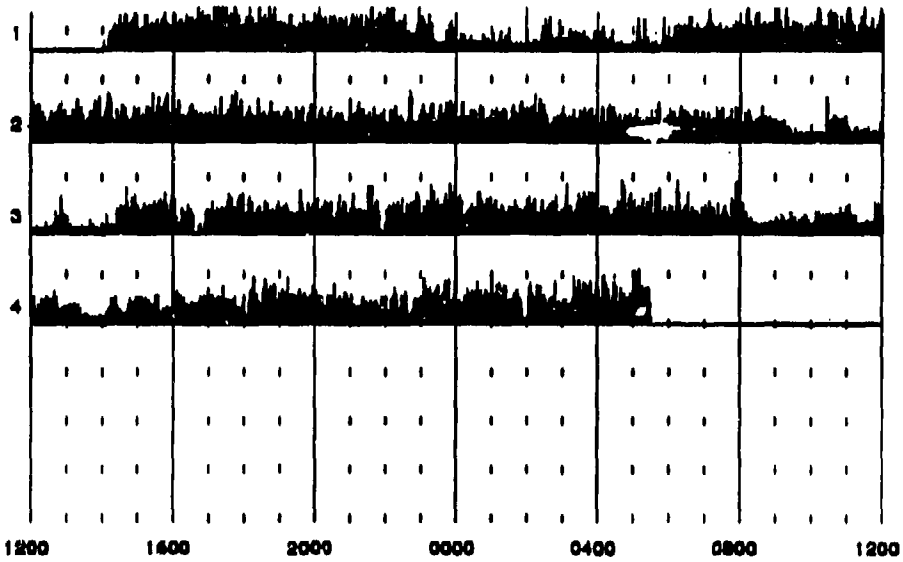
bumps in the groove of a phonograph record. The actigraph contains electronic circuitry for sensing this analog voltage and converting it to digital pulses which are in turn stored in an on-board memory. In the AMA-32 (but not the AMA-16), the parameters of this analog-to-digital conversion (frequency passband, amplifier gain, and voltage threshold) are programmable. Details are available in the documentation for PCD.EXE. For reliable operation, the AMA-32 battery should be replaced after about two weeks of data collection. During data collection, activity is accumulated in "epochs" of time. That is, the number of movements occurring in each epoch is counted and stored.

Interaction with the AMA-32 is accomplished with an Actigraph Interface Unit (AIU) connected to a serial port on an IBM-compatible PC. The menu-driven PCD.EXE program has routines for initializing actigraphs, monitoring their operation, and downloading data from the actigraph into the PC. Initialization parameters include a "packing option" (memory bits per epoch), the data collection epoch, data collection start time and date, current time and date, amplifier setting, and data identifier. The duration of a data collection run depends on the amount of memory in a given actigraph (16 or 32 Kbytes) and the data packing option. In general, since more activity occurs in longer epochs, more memory space is required to store the data, thus requiring a larger packing option (more bits per epoch). The most commonly used epoch duration is 60 seconds. With a 16 Kbyte memory, one byte per epoch and 60 sec epochs, approximately 11 days of data can be collected before the actigraph memory is filled. With the 32 Kbyte memory in the AMA-32, approximately 22 days of data can be stored.

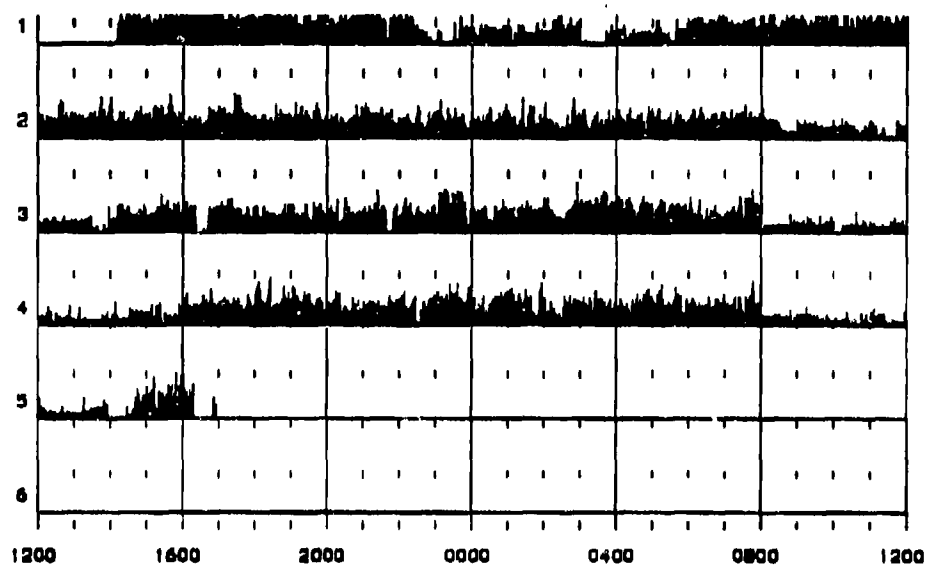
The both the AMA-16 and the AMA-32 can actually be operated in two different modes, zero crossing (ZC) and time above threshold (TAT). Virtually all of the work that has been done has used the ZC mode. In this mode, two counts are generated for each movement, one when the voltage output from the accelerometer exceeds the threshold, and one when it falls back below the threshold. While usually counts begin and end in the same epoch and only occasionally, will a movement will begin in one epoch and end in the next. This results in an inappropriately high number of epochs with an even number of counts. To correct for this artifact, if ZC mode is in effect, the data from each epoch are corrected while the file is being read, resulting in only one count per movement. The formula for this correction is:

NEW_VALUE = INTEGER ((OLD_VALUE + 1) / 2)

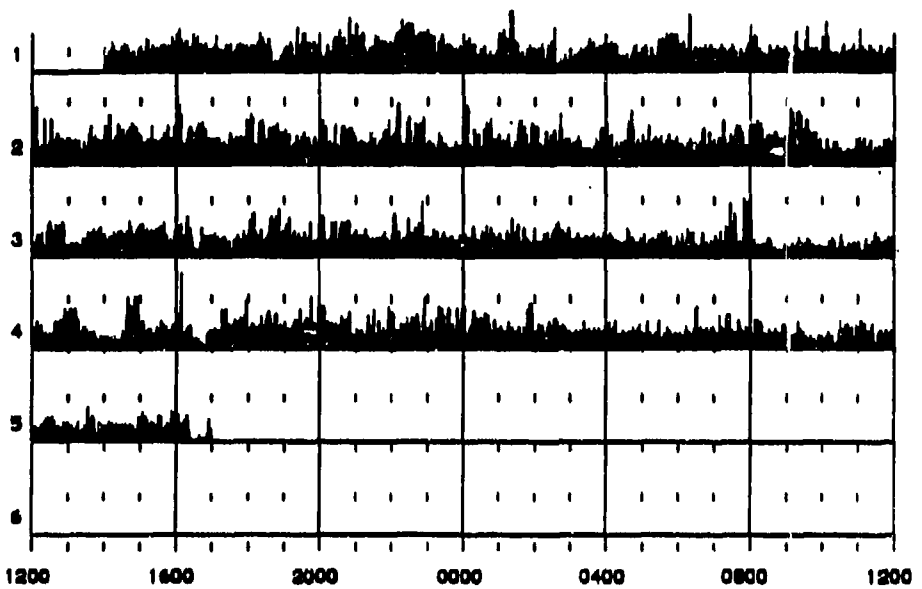
In TAT mode, movement duration is recorded by accumulating the time in tenths of a second that the voltage remains above threshold.



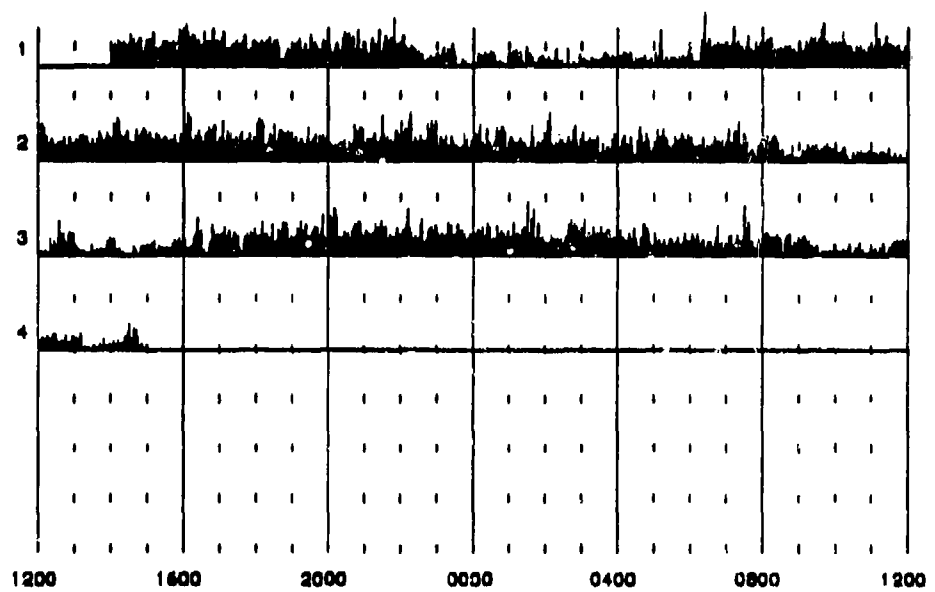
File: BL201-5.DAT, Epoch: 30, Amplifier: 05, Scale: 100
Starting Time: Jul 13, 1992, 14:00:00, SN:0053



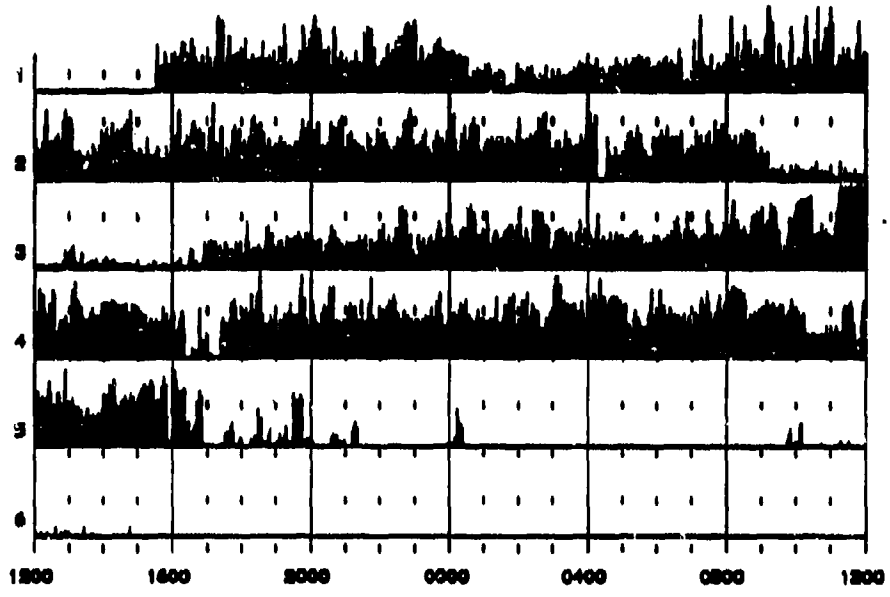
File: BL201-6.DAT, Epoch: 30, Amplifier: 06, Scale: 100
Starting Time: Jul 13, 1992, 14:00:00, SN:0057



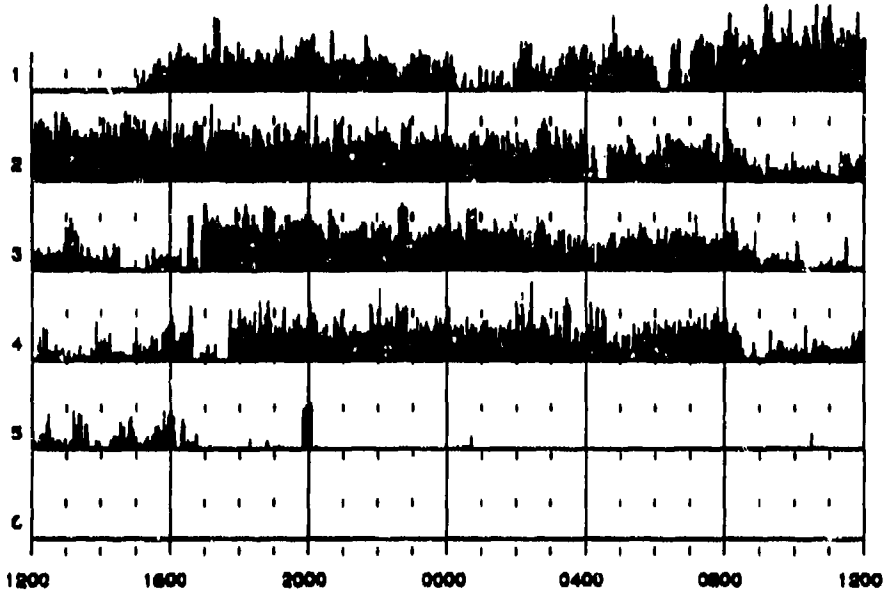
File: BL203-5.DAT, Epoch: 30, Amplifier: 05, Scale: 100
Starting Time: Jul 13, 1992, 14:00:00, SN: 61



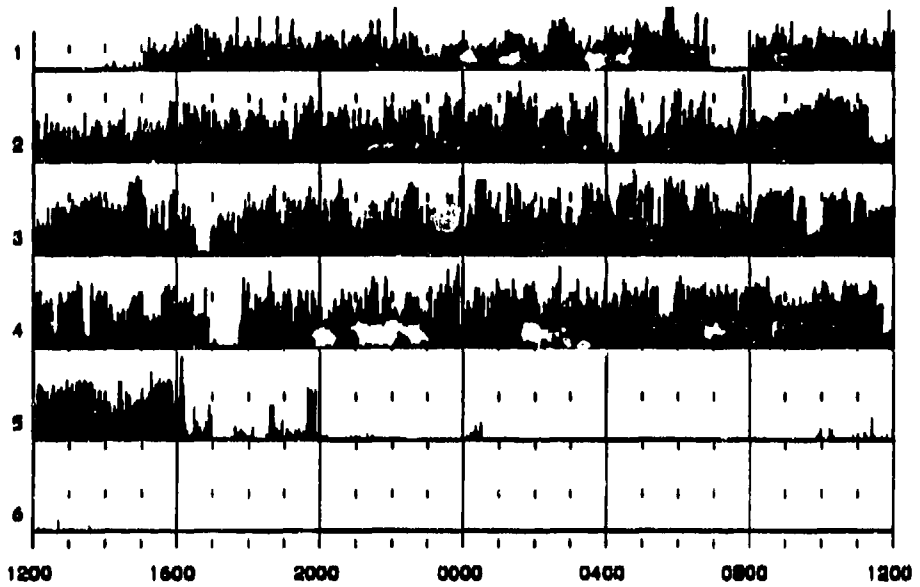
File: BL203-6.DAT, Epoch: 30, Amplifier: 06, Scale: 100
Starting Time: Jul 13, 1992, 14:00:00, SN:0062



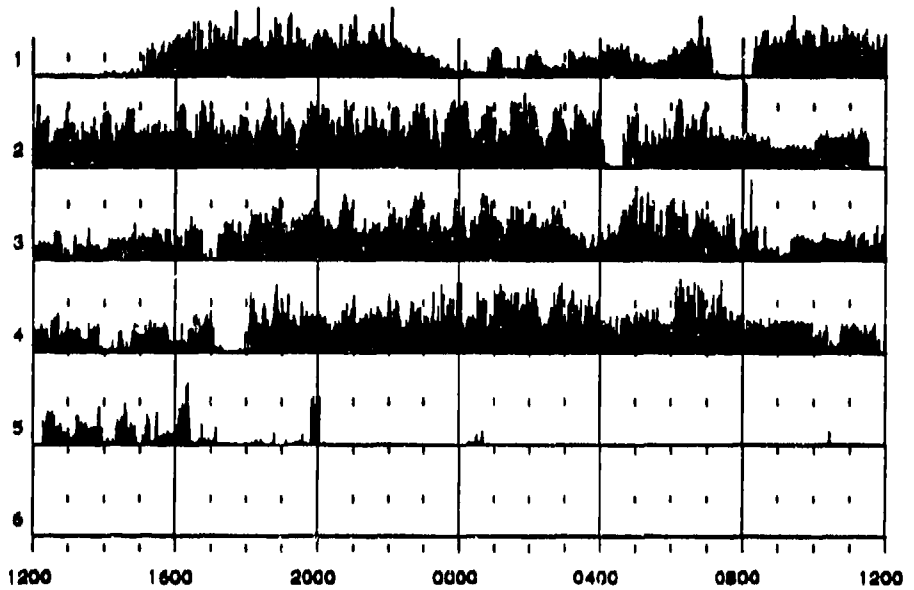
File: BL205-9.DAT, Epoch: 30, Amplifier: 09, Scale: 100
Starting Time: Jul 29, 1992, 15:30:00, SN:0056



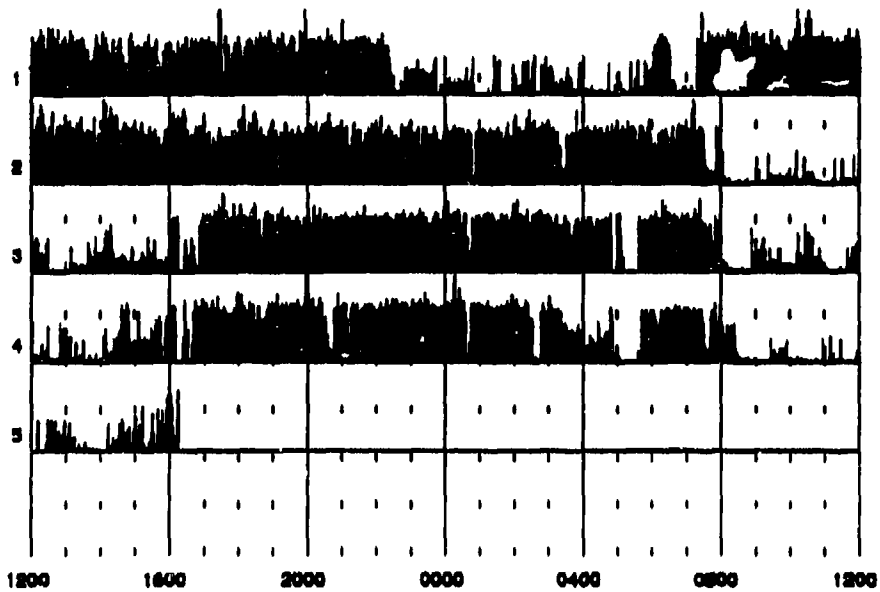
File: BL205-10.DAT, Epoch: 30, Amplifier: 10, Scale: 100
Starting Time: Jul 30, 1992, 14:00:00, SN:0060



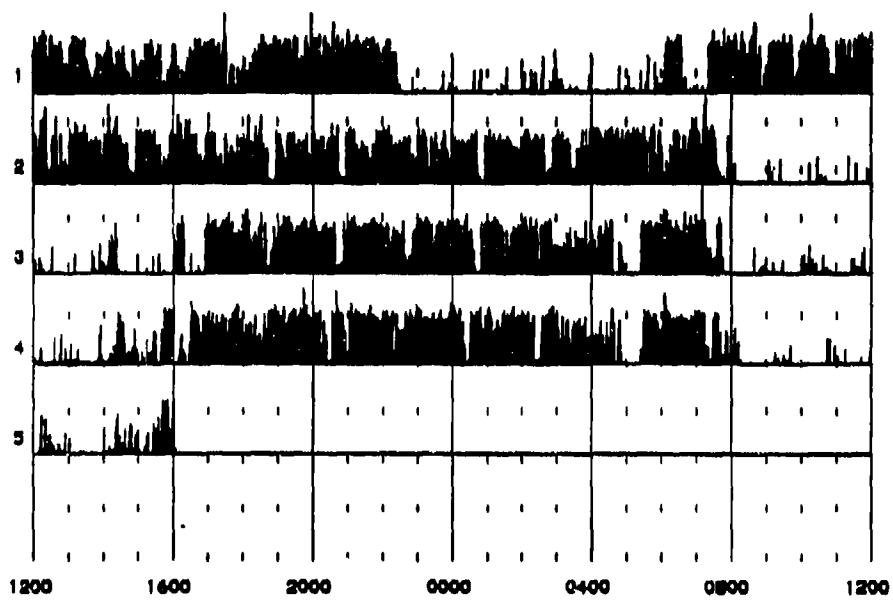
File: BL206-9.DAT, Epoch: 30, Amplifier: 09, Scale: 100
Starting Time: Jul 20, 1992, 14:00:00, SN: 61



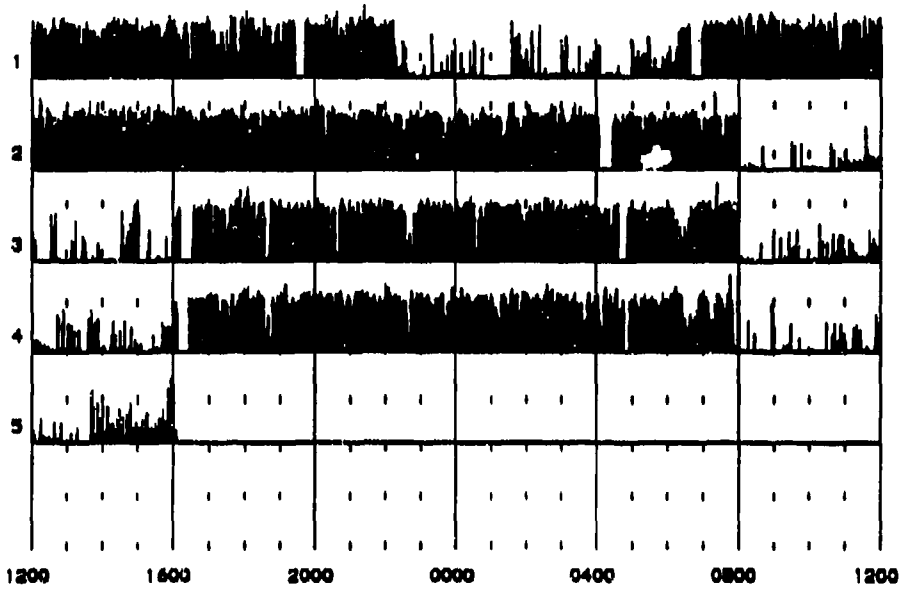
File: BL206-10.DAT, Epoch: 30, Amplifier: 10, Scale: 100
Starting Time: Jul 20, 1992, 14:00:00, SN:0062



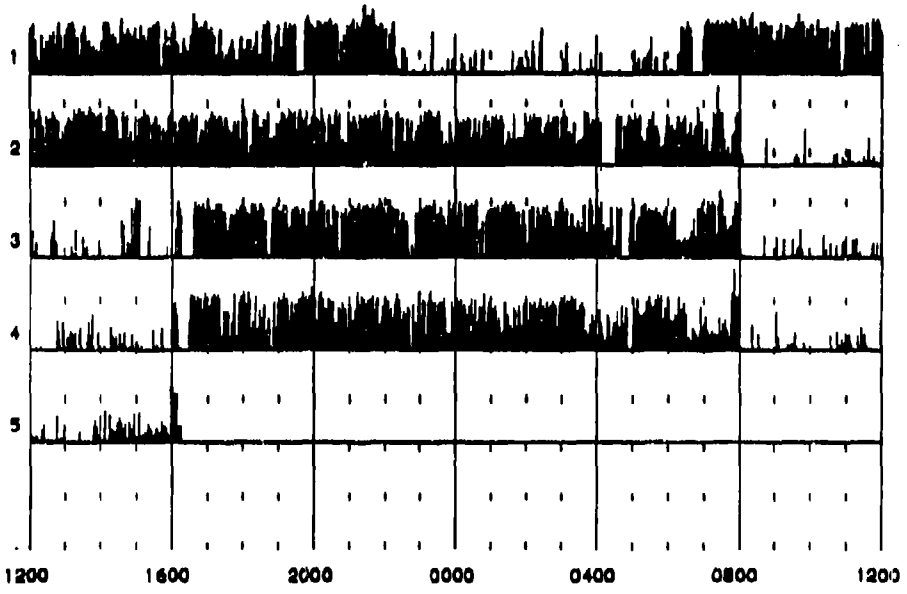
File: BL207-17.DAT, Epoch: 30, Amplifier: 17, Scale: 100
Starting Time: Aug 10, 1992, 12:00:00, SN:0053



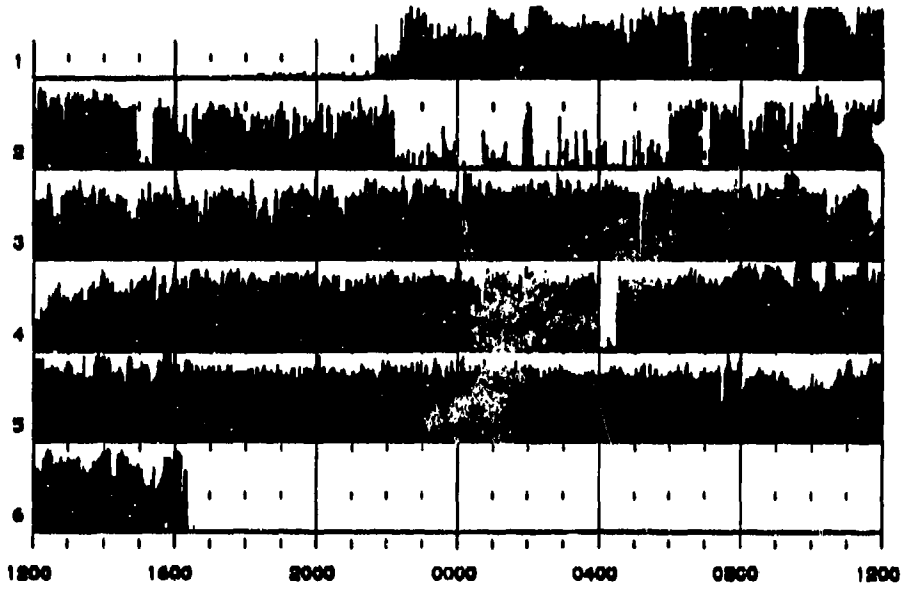
File: BL207-18.DAT, Epoch: 30, Amplifier: 18, Scale: 100
Starting Time: Aug 10, 1992, 12:00:00, SN:0054



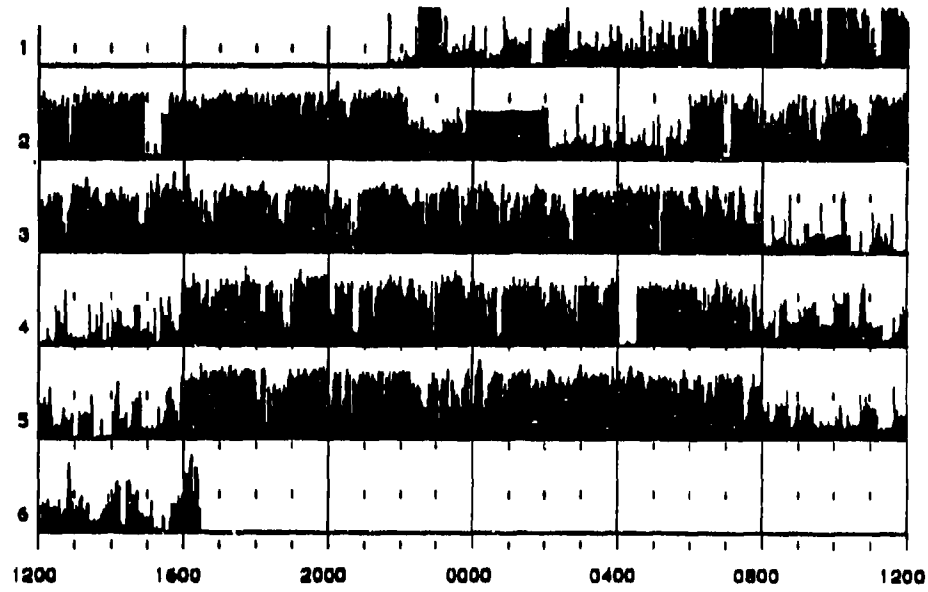
File: BL20B-17.DAT, Epoch: 30, Amplifier: 17, Scale: 100
Starting Time: Aug 10, 1992, 12:00:00, SN:0035



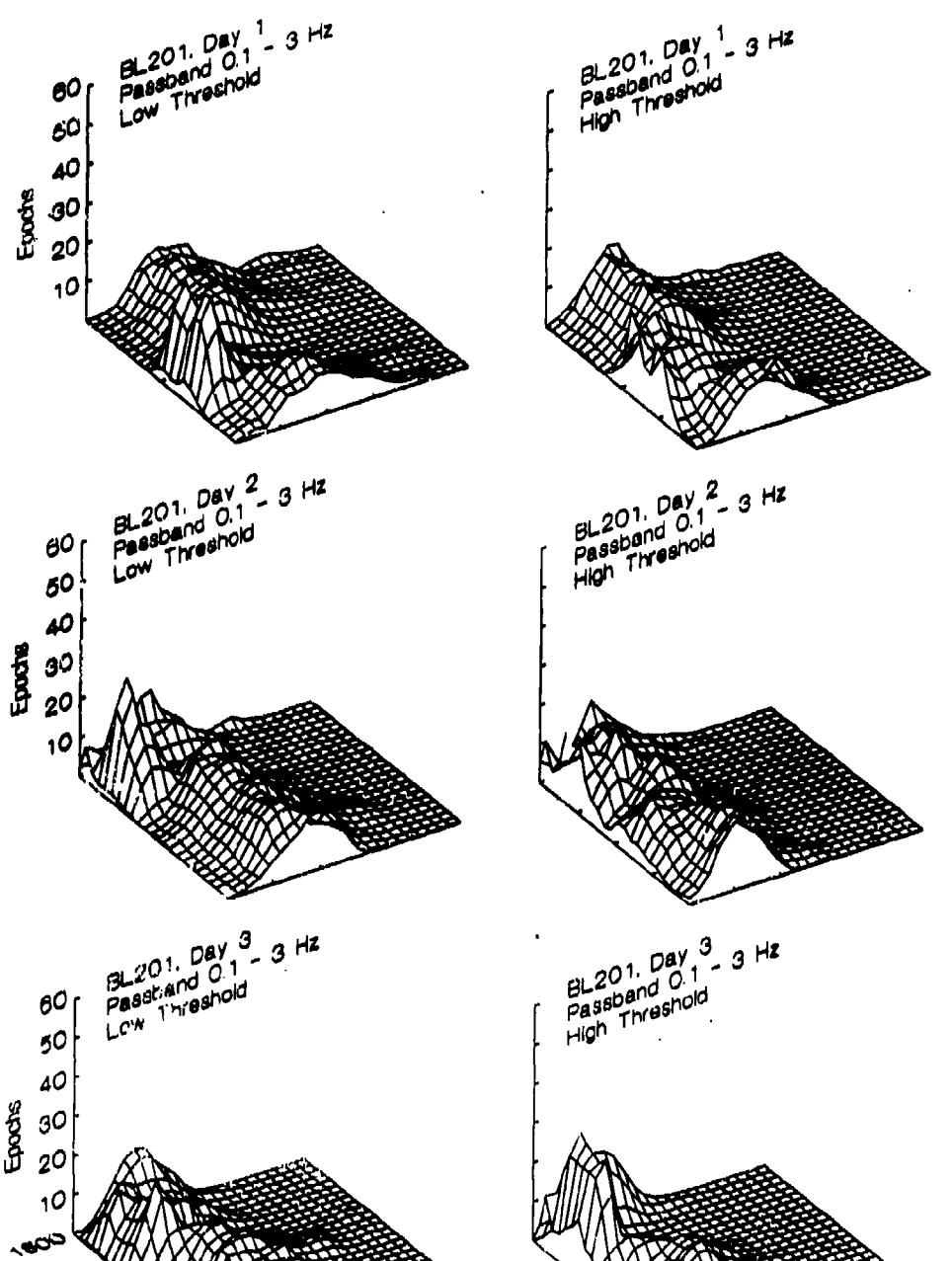
File: BL20B-18.DAT, Epoch: 30, Amplifier: 18, Scale: 100
Starting Time: Aug 10, 1992, 12:00:00, SN:0036

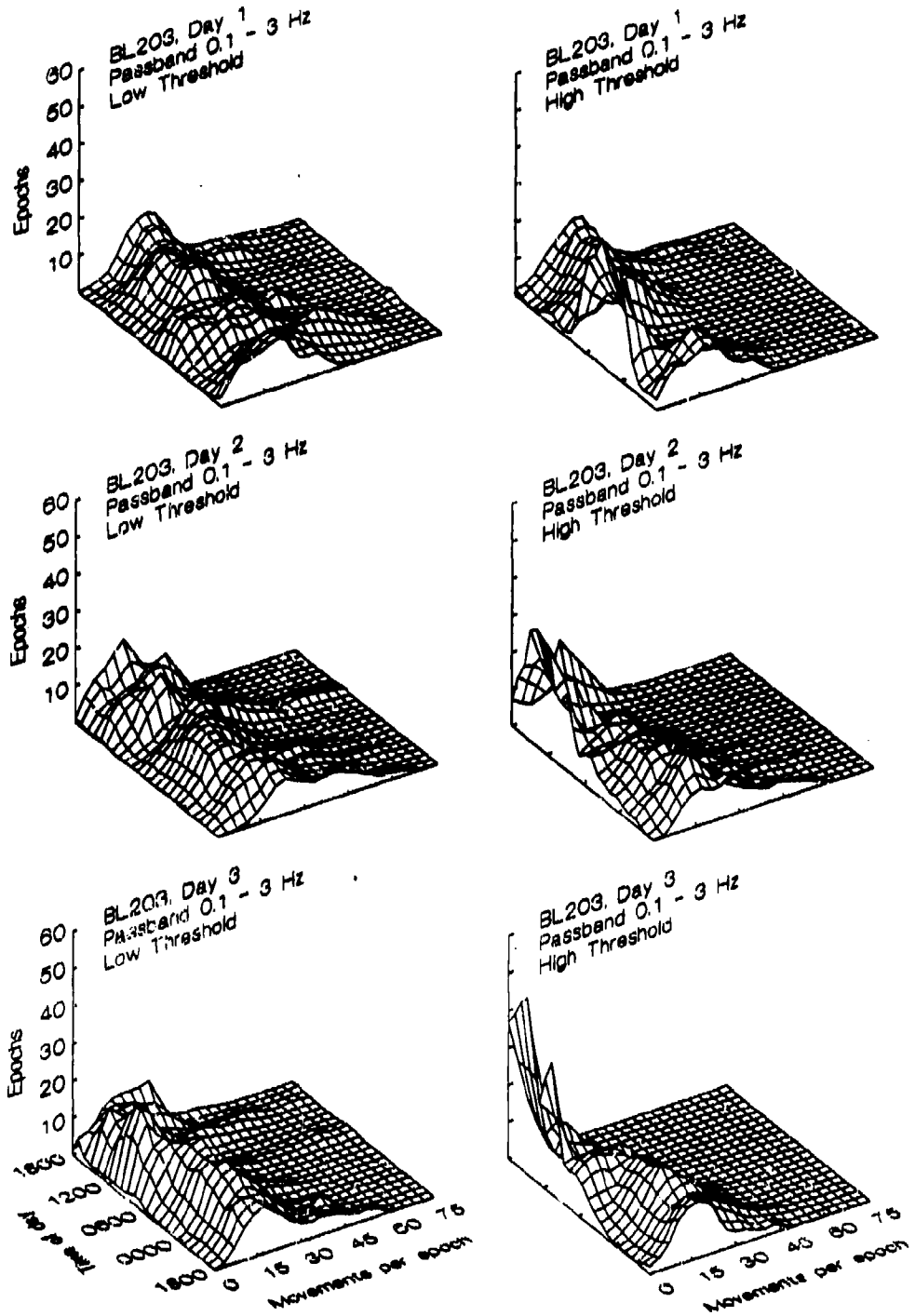


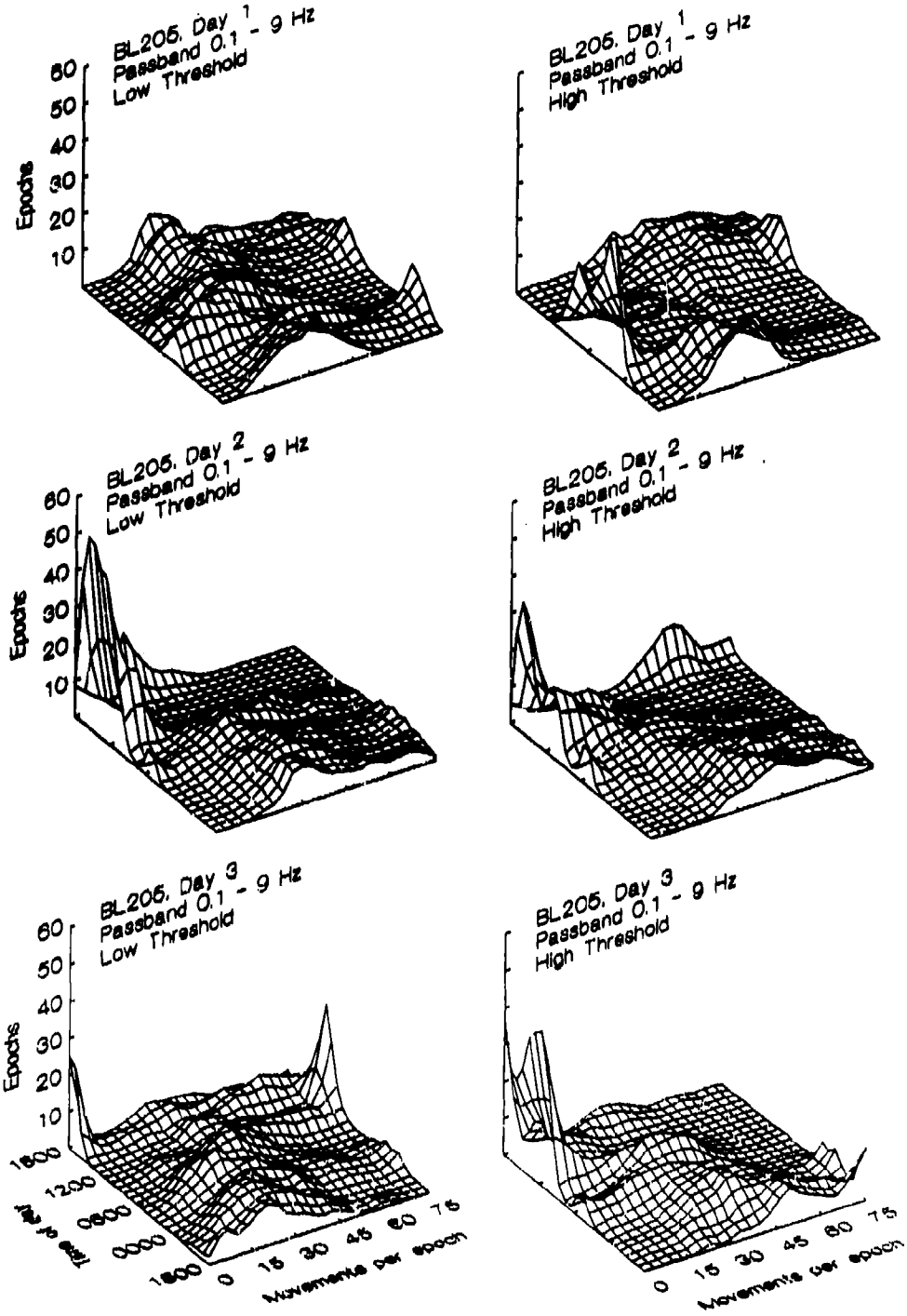
File: BL210-19.DAT, Epoch: 30, Amplifier: 19, Scale: 100
Starting Time: Aug 16, 1992, 18:00:00, SN:0053

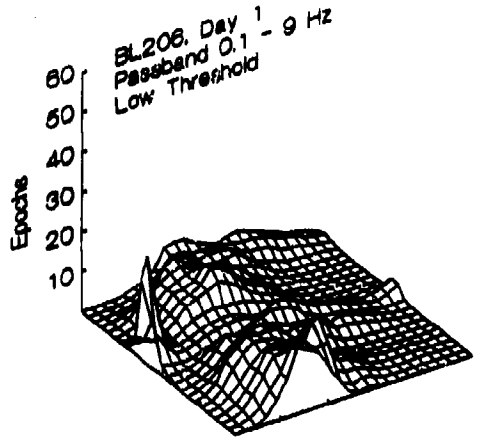


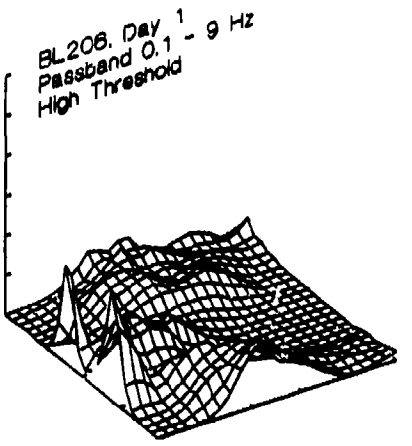
File: BL210-20.DAT, Epoch: 30, Amplifier: 20, Scale: 100
Starting Time: Aug 16, 1992, 18:00:00, SN:0054

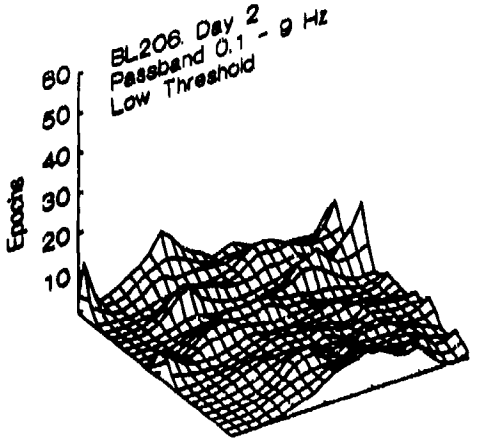

BL201. Day 1
Passband 0.1 - 3 Hz
Low Threshold
BL201. Day 1
Passband 0.1 - 3 Hz
High Threshold
BL201. Day 2
Passband 0.1 - 3 Hz
Low Threshold
BL201. Day 2
Passband 0.1 - 3 Hz
High Threshold
BL201. Day 3
Passband 0.1 - 3 Hz
Low Threshold
BL201. Day 3
Passband 0.1 - 3 Hz
High Threshold
Epochs
60
50
40
30
20
10
1600
1200
0800
0400
0000
1600
0
15
30
45
60
75
Movements per epoch

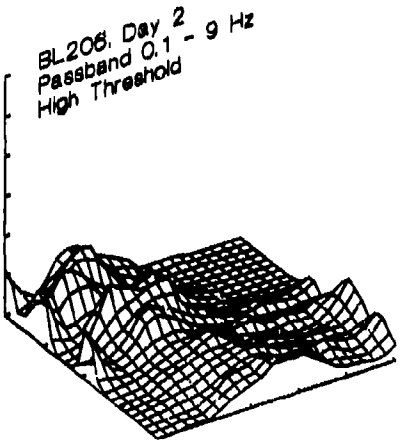

BL203, Day 1
Passband 0.1 - 3 Hz
Low Threshold
BL203, Day 1
Passband 0.1 - 3 Hz
High Threshold
BL203, Day 2
Passband 0.1 - 3 Hz
Low Threshold
BL203, Day 2
Passband 0.1 - 3 Hz
High Threshold
BL203, Day 3
Passband 0.1 - 3 Hz
Low Threshold
BL203, Day 3
Passband 0.1 - 3 Hz
High Threshold
Epochs
60
50
40
30
20
10
1800
1200
0600
0000
1800
0
15
30
45
60
75
Movements per epoch

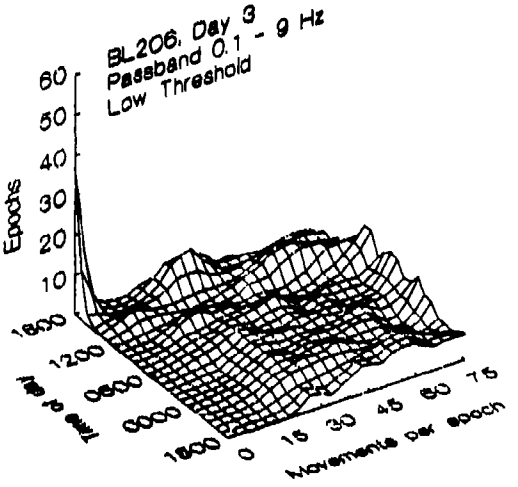

BL205, Day 1
Passband 0.1 - 9 Hz
Low Threshold
BL205, Day 1
Passband 0.1 - 9 Hz
High Threshold
BL205, Day 2
Passband 0.1 - 9 Hz
Low Threshold
BL205, Day 2
Passband 0.1 - 9 Hz
High Threshold
BL205, Day 3
Passband 0.1 - 9 Hz
Low Threshold
BL205, Day 3
Passband 0.1 - 9 Hz
High Threshold
Epochs
60
50
40
30
20
10
1800
1200
0600
0000
1800
0
15
30
45
60
75
Movements per epoch

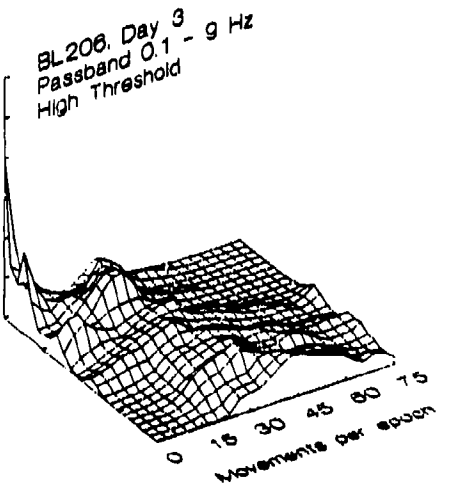

BL206, Day 1
Passband 0.1 - 9 Hz
Low Threshold
Epochs
60
50
40
30
20
10

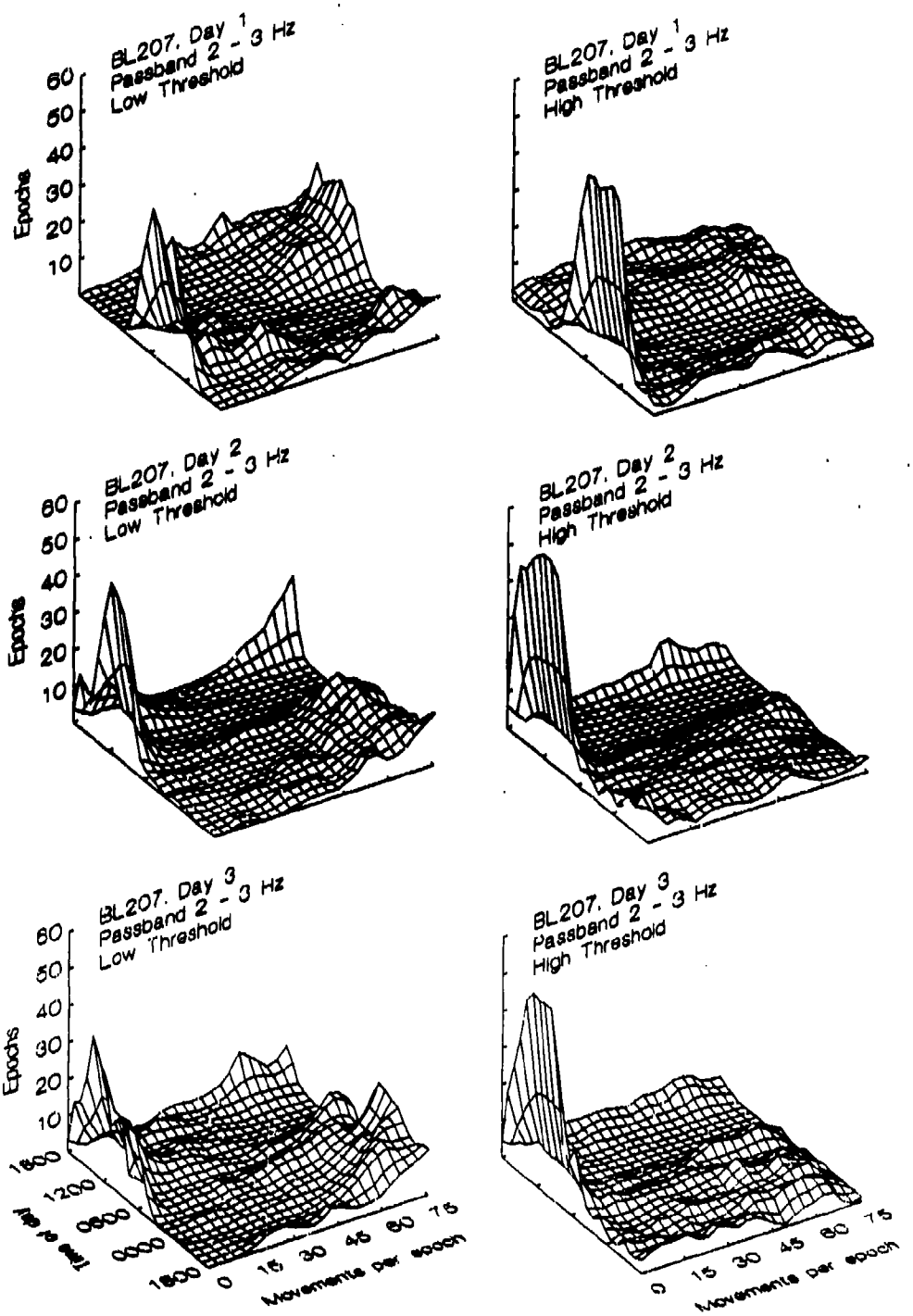

BL206, Day 1
Passband 0.1 - 9 Hz
High Threshold

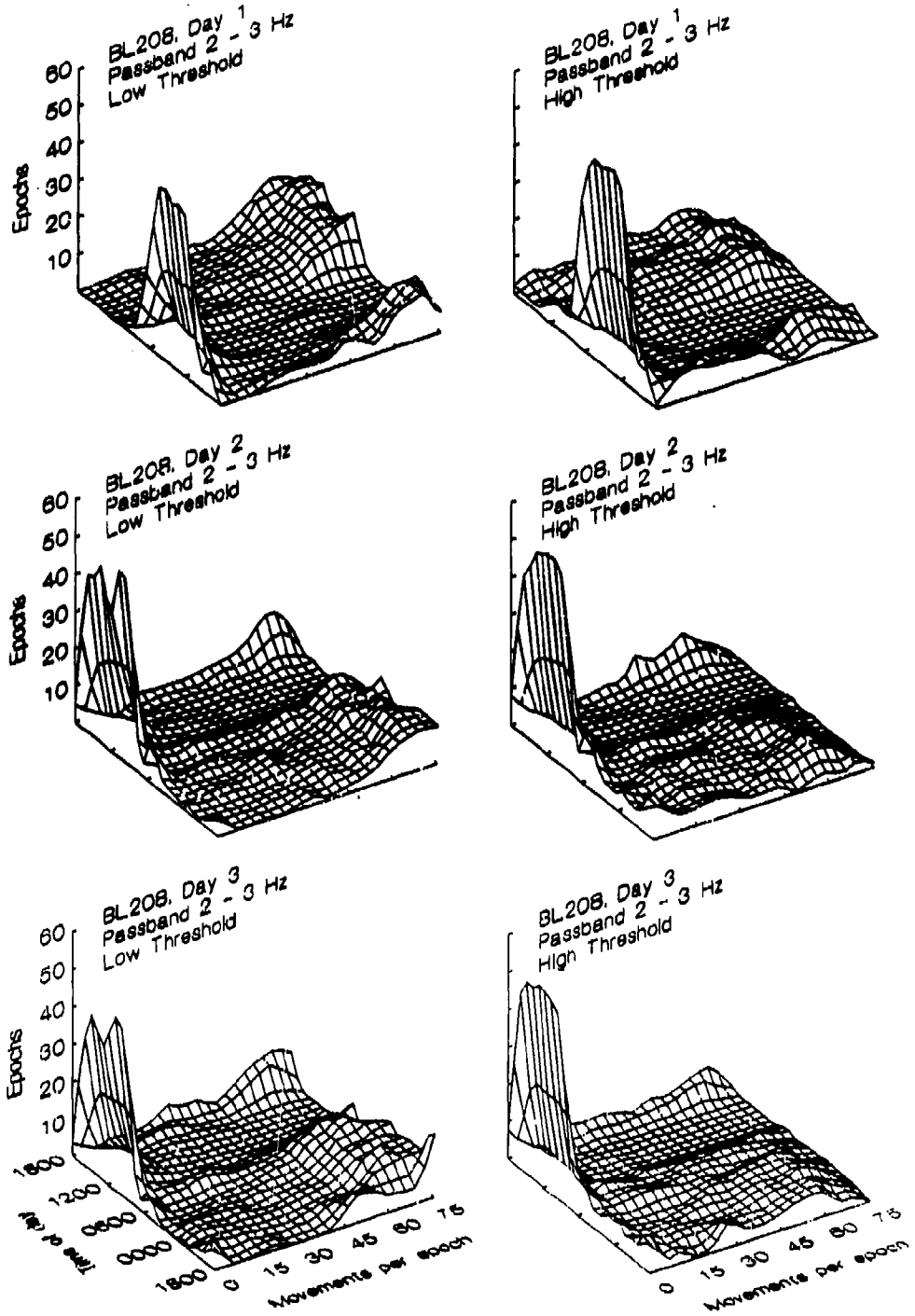

BL206, Day 2
Passband 0.1 - 9 Hz
Low Threshold
Epochs
60
50
40
30
20
10

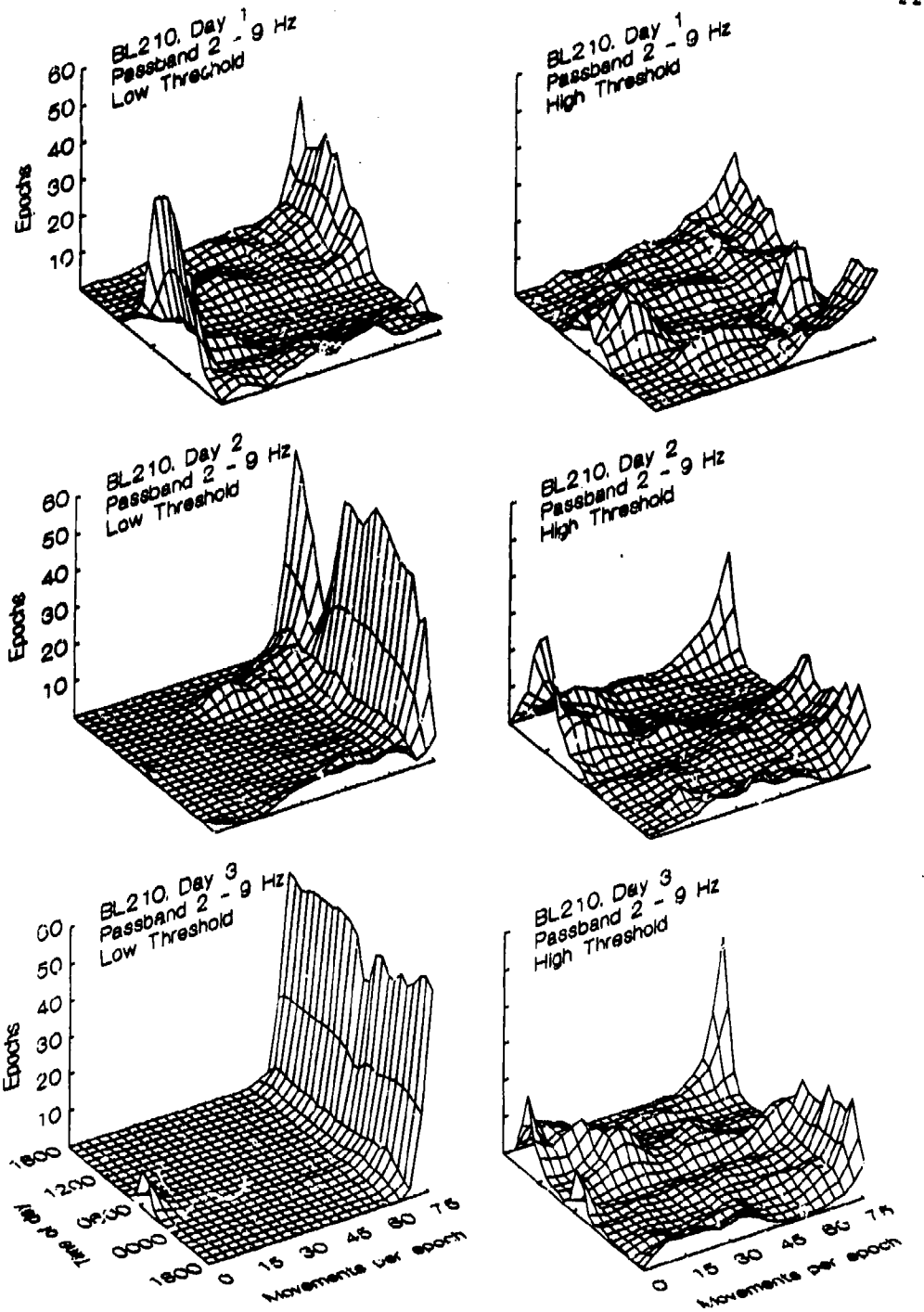

BL206, Day 2
Passband 0.1 - 9 Hz
High Threshold

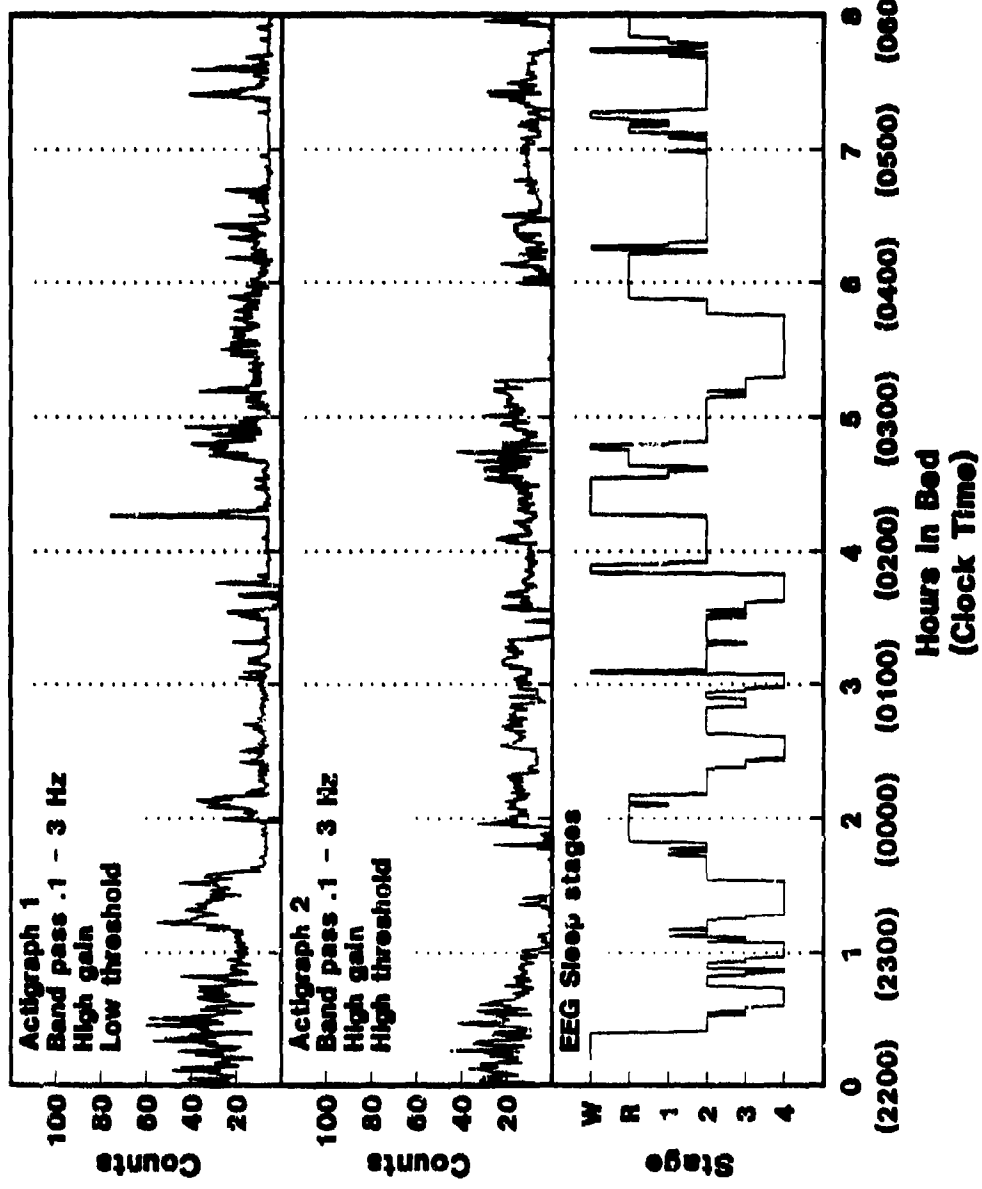

BL206, Day 3
Passband 0.1 - 9 Hz
Low Threshold
Epochs
60
50
40
30
20
10
1800
1200
0600
0000
1800
Time of day
0
15
30
45
60
75
Movements per epoch

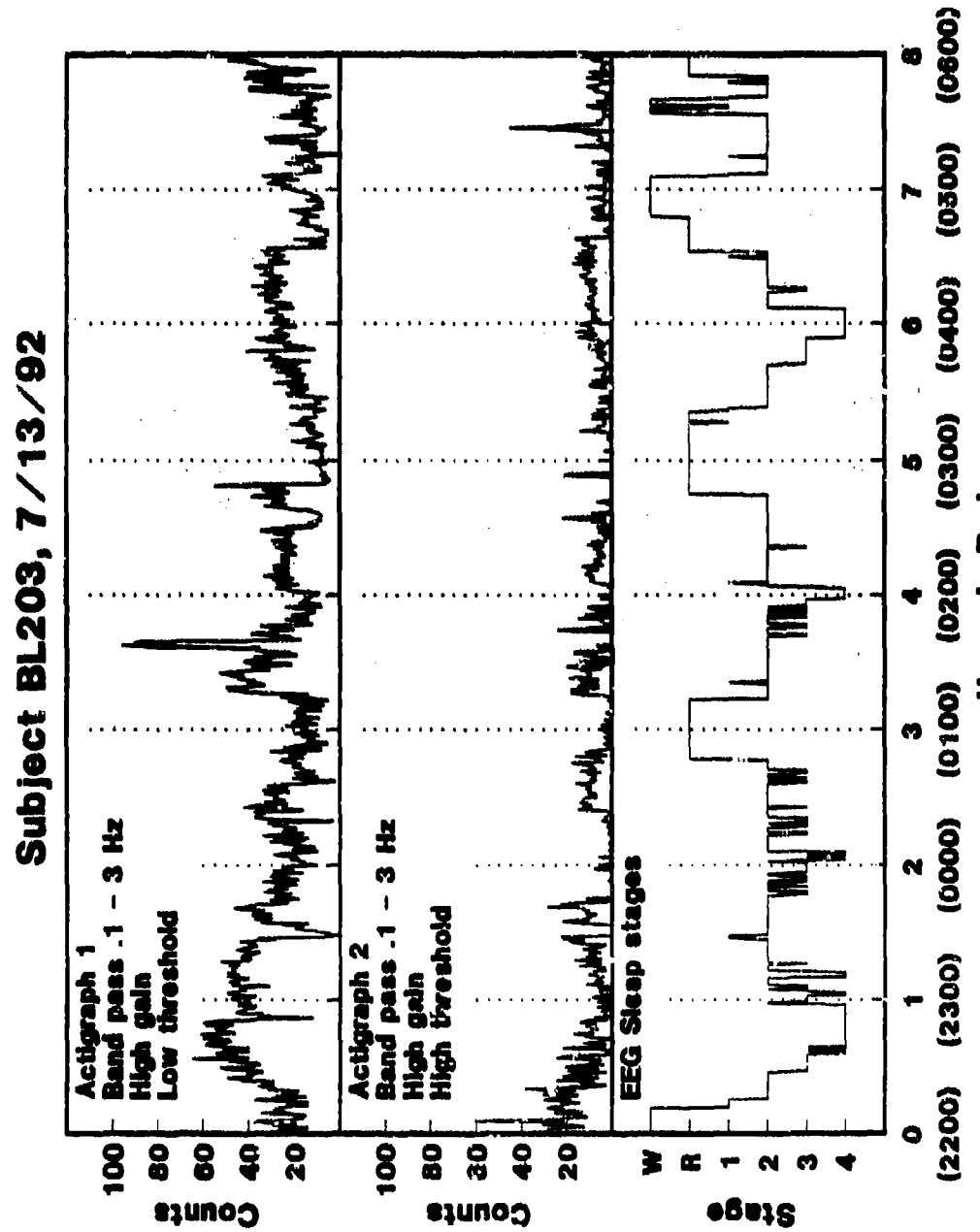

BL206, Day 3
Passband 0.1 - 9 Hz
High Threshold
0
15
30
45
60
75
Movements per epoch

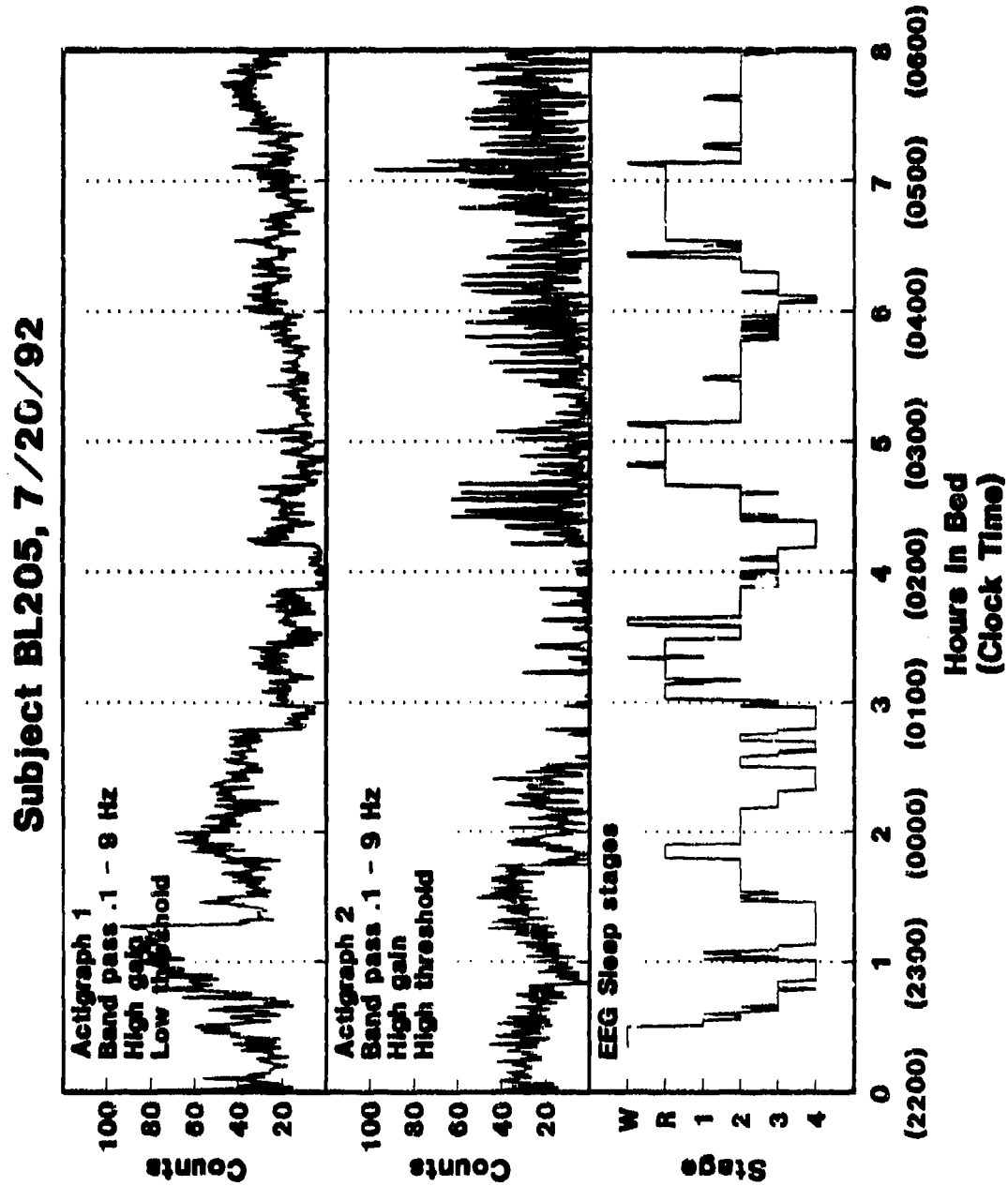

BL207, Day 1
Passband 2 - 3 Hz
Low Threshold
BL207, Day 1
Passband 2 - 3 Hz
High Threshold
BL207, Day 2
Passband 2 - 3 Hz
Low Threshold
BL207, Day 2
Passband 2 - 3 Hz
High Threshold
BL207, Day 3
Passband 2 - 3 Hz
Low Threshold
BL207, Day 3
Passband 2 - 3 Hz
High Threshold
Epochs
60
50
40
30
20
10
1800
1200
0600
0000
1800
0
15
30
45
60
75
Movements per epoch

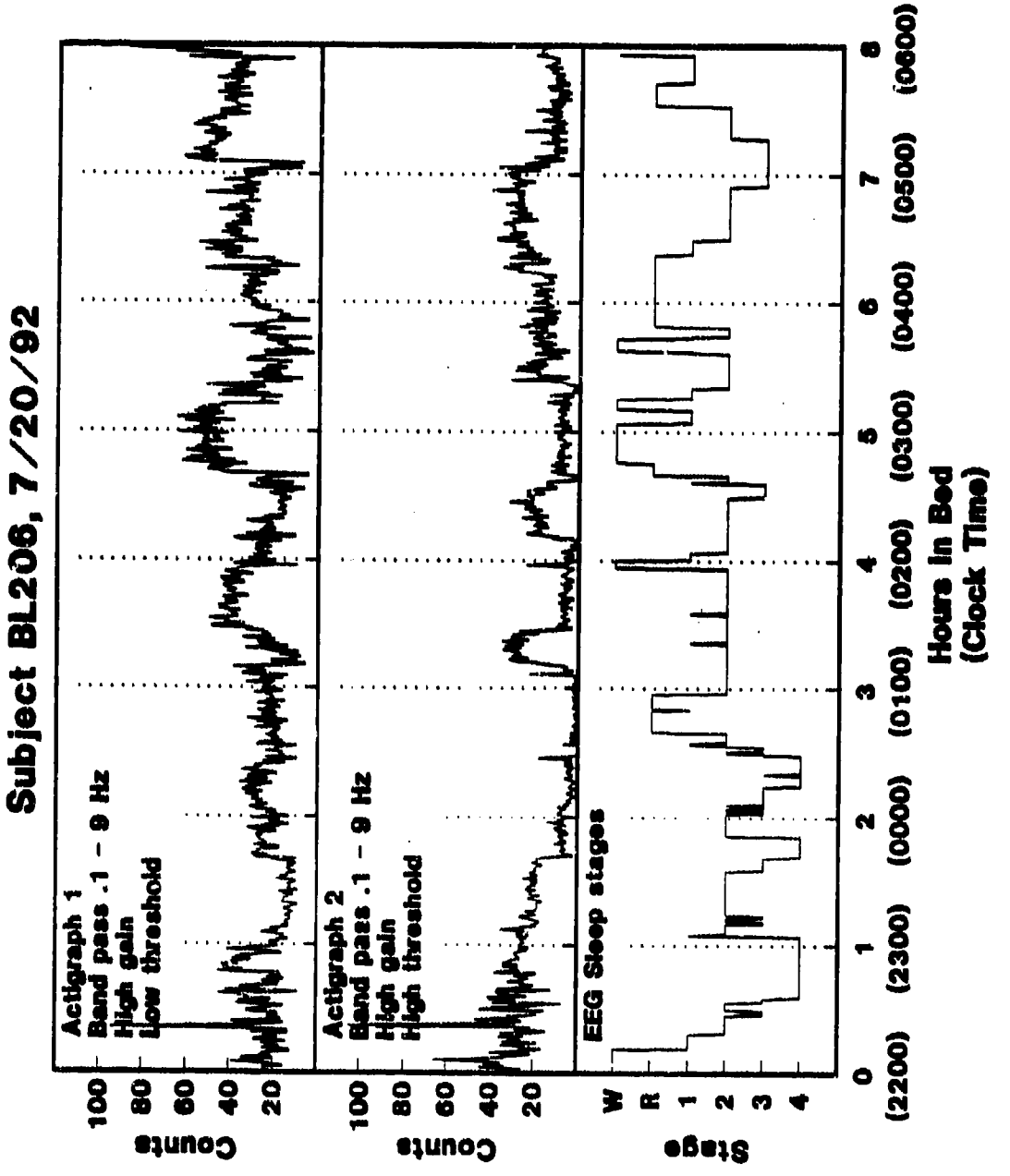

BL208, Day 1
Passband 2 - 3 Hz
Low Threshold
BL208, Day 1
Passband 2 - 3 Hz
High Threshold
BL208, Day 2
Passband 2 - 3 Hz
Low Threshold
BL208, Day 2
Passband 2 - 3 Hz
High Threshold
BL208, Day 3
Passband 2 - 3 Hz
Low Threshold
BL208, Day 3
Passband 2 - 3 Hz
High Threshold
Epochs
60
50
40
30
20
10
Time of Day
1800
1200
0600
0000
1800
0
15
30
45
60
75
Movements per epoch

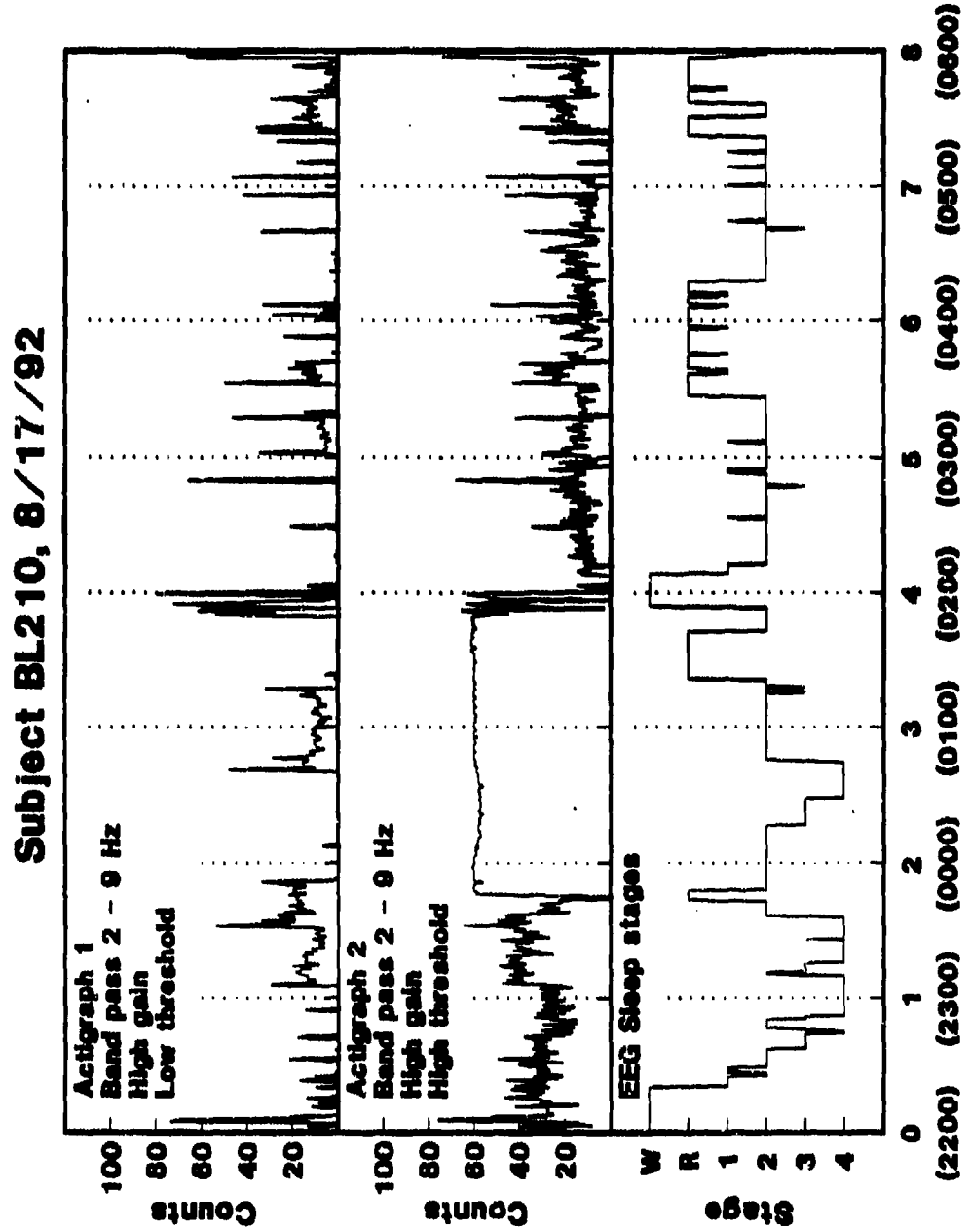

BL210. Day 1
Passband 2 - 9 Hz
Low Threshold
BL210. Day 1
Passband 2 - 9 Hz
High Threshold
BL210. Day 2
Passband 2 - 9 Hz
Low Threshold
BL210. Day 2
Passband 2 - 9 Hz
High Threshold
BL210. Day 3
Passband 2 - 9 Hz
Low Threshold
BL210. Day 3
Passband 2 - 9 Hz
High Threshold
Epochs
60
50
40
30
20
10
1800
1200
0600
0000
1800
0
15
30
45
60
75
Movements per epoch

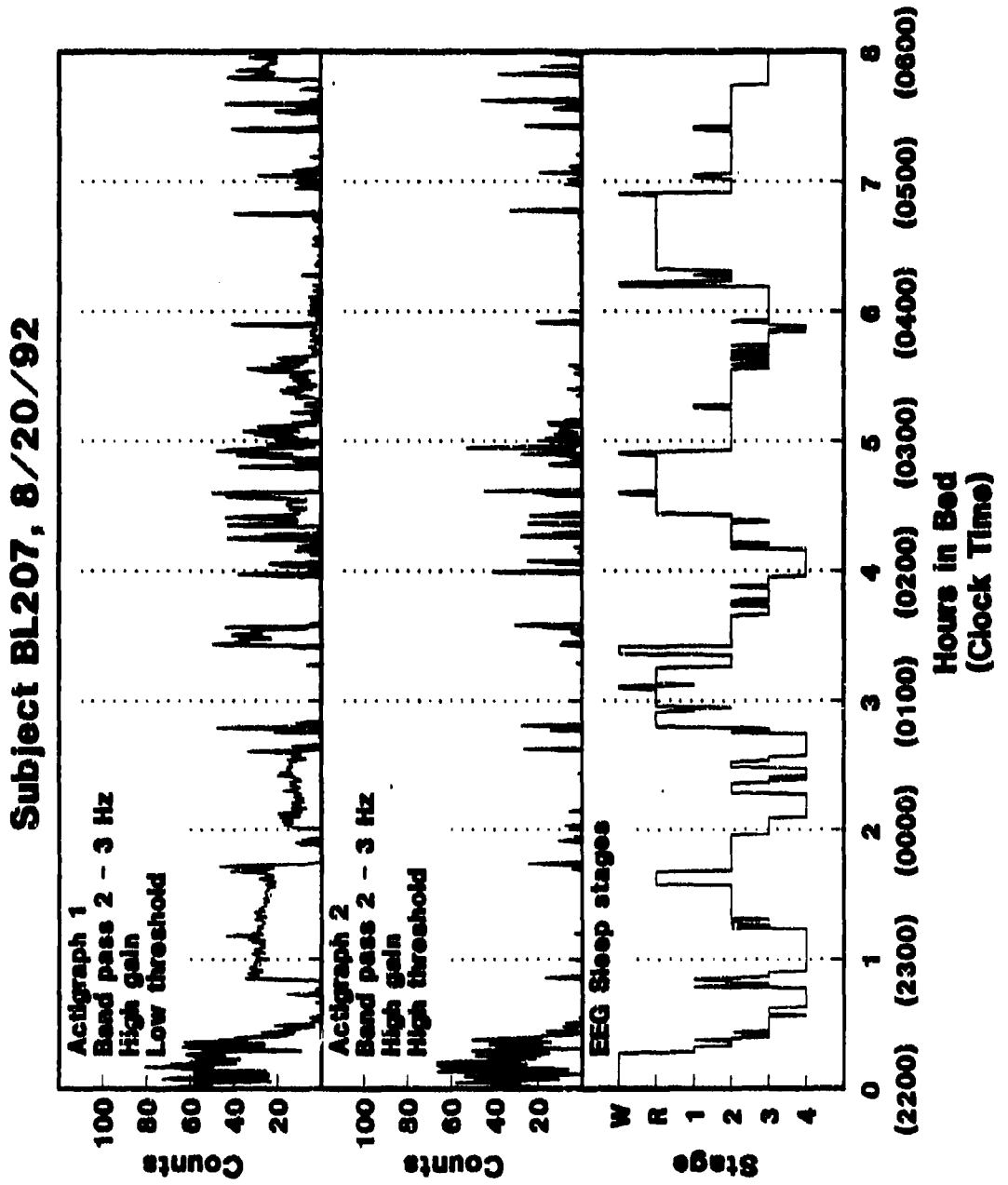

Subject BL201, 7/13/92
Actigraph 1
Band pass .1 - 3 Hz
High gain
Low threshold
Counts
Actigraph 2
Band pass .1 - 3 Hz
High gain
High threshold
Counts
EEG Sleep stages
Stage
W
R
1
2
3
4
0 (2200)
1 (2300)
2 (0000)
3 (0100)
4 (0200)
5 (0300)
6 (0400)
7 (0500)
8 (0600)
Hours in Bed
(Clock Time)

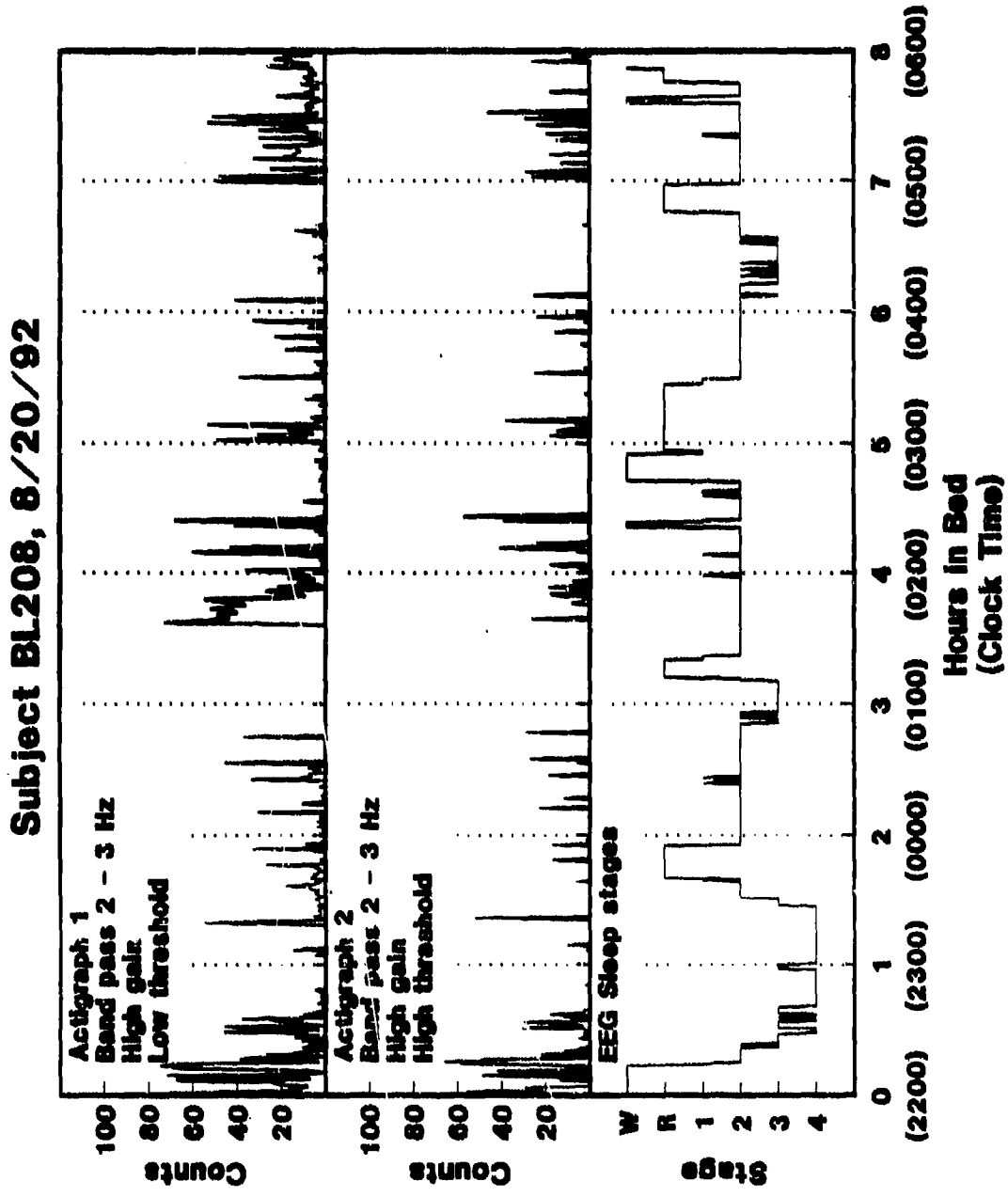

Subject BL203, 7/13/92
Actigraph 1
Band pass .1 - 3 Hz
High gain
Low threshold
Counts
100
80
60
40
20
Actigraph 2
Band pass .1 - 3 Hz
High gain
High threshold
Counts
100
80
60
40
20
EEG Sleep stages
Stage
W
R
1
2
3
4
0 (2200)
1 (2300)
2 (0000)
3 (0100)
4 (0200)
5 (0300)
6 (0400)
7 (0300)
8 (0600)
Hours In Bed
(Clock Time)


Subject BL205, 7/20/92
Actigraph 1
Band pass .1 - 8 Hz
High gain
Low threshold
Actigraph 2
Band pass .1 - 9 Hz
High gain
High threshold
EEG Sleep stages
Counts
Stage
W
R
1
2
3
4
0 (2200)
1 (2300)
2 (0000)
3 (0100)
4 (0200)
5 (0300)
6 (0400)
7 (0500)
8 (0600)
Hours in Bed
(Clock Time)


Subject BL206, 7/20/92
Actigraph 1
Band pass .1 - 9 Hz
High gain
Low threshold
Counts
Actigraph 2
Band pass .1 - 9 Hz
High gain
High threshold
Counts
EEG Sleep stages
Stage
W
R
1
2
3
4
0 (2200)
1 (2300)
2 (0000)
3 (0100)
4 (0200)
5 (0300)
6 (0400)
7 (0500)
8 (0600)
Hours in Bed
(Clock Time)


Subject BL210, 8/17/92
Actigraph 1
Band pass 2 - 9 Hz
High gain
Low threshold
Actigraph 2
Band pass 2 - 9 Hz
High gain
High threshold
EEG Sleep stages
Counts
Stage
W
R
1
2
3
4
0 (2200) 1 (2300) 2 (0000) 3 (0100) 4 (0200) 5 (0300) 6 (0400) 7 (0500) 8 (0600)
Hours in Bed
(Clock Time)


Subject BL207, 8/20/92
Actigraph 1
Band pass 2 - 3 Hz
High gain
Low threshold
Actigraph 2
Band pass 2 - 3 Hz
High gain
High threshold
EEG Sleep stages
Counts
Stage
W
R
1
2
3
4
100
80
60
40
20
0
1
2
3
4
5
6
7
8
(2200)
(2300)
(0000)
(0100)
(0200)
(0300)
(0400)
(0500)
(0600)
Hours in Bed
(Clock Time)


Subject BL208, 8/20/92
Actigraph 1
Band pass 2 - 3 Hz
High gain
Low threshold
Actigraph 2
Band pass 2 - 3 Hz
High gain
High threshold
EEG Sleep stages
Counts
Stage
W
R
1
2
3
4
0 (2200)
1 (2300)
2 (0000)
3 (0100)
4 (0200)
5 (0300)
6 (0400)
7 (0500)
8 (0600)
Hours in Bed
(Clock Time)

REPORT DOCUMENTATION PAGE

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6. AUTHOR(S)
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11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This project investigated some properties of the AMA-32 wrist-worn activity monitor. In the first phase of this project, a software program for the analysis of activity data was developed. The program permits rapid statistical and graphical summaries of activity data. The second phase of the project investigated effects of varying the sensitivity of the actigraph. Three different frequency passbands were investigated. The ability to differentiate sleep from wake was optimized with a 2 to 3 Hz passband, particularly with a high trigger threshold. Increasing sensitivity by lowering the trigger threshold or by broadening the passband reduced sleep/wake discriminability. The optimal sleep/wake discrimination parameters for the AMA-32 approximate those of earlier generations of wrist-worn actigraphs. The work in this report suggests research to investigate the utility of other actigraph sensitivity settings for differentiating movement patterns during sleep or for assessments of daytime workload.

14. SUBJECT TERMS	15. NUMBER OF PAGES
activity, actigraph, sleep, circadian rhythms, ambulatory monitoring	60
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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